PETROLOGICAL STUDIES IN GLEN URQUHART, INVERNESS-SHIRE

I. LIMESTONES   II. SKARNS

INTRODUCTION

THE area in which lie the rocks to be described in this *Bulletin* is partly in Glen Urquhart, partly on the moors immediately north of the glen. In the valley sides it extends from Polmaily House to Drumnadrochit, and on the moors between Loch Gorm and Garbeg Farm (Map, Pl. 10 at the end of this *Bulletin*). The majority of the ground is underlain by metasedimentary rock comprising (in structural succession) a bed of siliceous magnesian limestone of which the uppermost 40 ft. are exposed, an argillaceous bed of perhaps the same thickness and a much thicker succession of arenaceous beds having no recognized top. This series contains basaltic rock in streaks and lenses, which by every gradation reach the scale of massive sills 15 ft. thick.

After the emplacement of the basaltic rock the whole assemblage suffered isoclinal folding and metamorphism under kyanite zone (low amphibolite facies) conditions. Shortly afterwards an ultrabasic mass intruded the metasediments, truncating or disturbing their fold structures (Francis, 1956a). Finally, metasomatism affected the sediments and the ultrabasic intrusive. Within the sediments this metasomatism finds its acme in sporadic areas of schists altered to the chemical composition of granite. The isoclinally folded bedding-plane foliation in the schists is traceable right through these " bosses " of granitized rock, and no intrusive granite is exposed. In and around the " bosses " the chief material added appears to be potassium, expressed in newly-formed microcline in the schists and in quartz–microcline–muscovite–biotite pegmatites. In areas further from the granite–gneiss " bosses " the metasomatism involves sodium rather than potassium. The uninjected arenaceous rocks are rich in soda and this phase is probably nothing but a redistribution of the soda of these rocks. Oligoclase-bearing pegmatites free from microcline, and oligoclase–porphyroblast schists characterize this zone. In sediments yet further from the bosses the only representatives of the injection are quartz veins. These have apparently been able freely to absorb wallrock materials. In traversing the argillaceous rock (kyanite schist) they have absorbed alumina (in the form of kyanite), and in traversing the limestone they have absorbed lime (in the form of calcium silicates). At the sedimentary contacts between kyanite schist and limestone, at the borders of the ultrabasic mass and within it these lime-silica-alumina-charged veins have deposited skarns. Hydrothermal bodies of both discrete and gradational character within the ultrabasic mass, equivalent to the skarns in the sediments, have already been described (Francis, 1955,

1956a). Part I of this *Bulletin* describes the limestones, Part II the various lime-silica-alumina skarns. The description of the basaltic rocks, now represented by amphibolites, and of the argillaceous and arenaceous rocks with their alkali metasomatism, and a consideration of structural and age problems of the area will be left to further publications.

<div align="center">PART I</div>

<div align="center">LIMESTONES</div>

Previous Work

The earliest account of the geology of Glen Urquhart to be traced is contained in *The Statistical Account of Inverness-shire* (1842) in which the parishes of Urquhart and Glen Moriston were described by the Rev. Jas. Doune Smith (who wrote his contribution in the year 1835). This careful summary records all of the chief rock groups of the glen: " stratified gneiss, serpentine ", and " grey and white primitive granular limestone ", together with some of their minerals.

The next account of the geology of the district which has been discovered is contained in M. Forster Heddle's papers : " Chapters on the Mineralogy of Scotland " (1878). In these papers descriptions and analyses are furnished of andesine, tremolite, and edenite in limestone and of other minerals in the remaining rock groups. Heddle adds some comments on the structure of the area :

> " The serpentine of Polmally is on the north-east wrapped round with an unusually plicated bed of granular limestone, so convoluted, and fractured, and cut up by dykes, that it is difficult to determine whether there be not a greater number of beds than one ".
> And
> " The lime has been quarried here and there where anticlines brought it to the surface."

The latter passage agrees with the findings of E. H. Cunningham Craig (1914 : 20), and the present writer, that the limestone occupies the bottom of the structural succession in the area. Heddle (1878 : 310) gives a list of minerals found in the limestone as follows :

tremolite	– common	pyrrhotite	– common
andesine	– rare	sphene	– very common
urquhartite		apatite	– rare
edenite	– common		

No reference to urquhartite has been traced in the records or catalogues of this Museum or elsewhere. Wallace (1886) records from Glen Urquhart the minerals listed by Heddle, and in addition chondrodite. No confirmation of the existence of this mineral in the glen was obtained by Heddle (1879), or by the present writer. The original specimen of this mineral (Greg & Lettsom, 1858 : 223) " from Loch Ness ", is still preserved in this Museum. An X-ray powder photograph confirms

its identification and does not support the contention that it it staurolite *var.* " xantholite ", as suggested by Heddle (1879) and by Read & Double (1935).[1]

The investigation of Glen Urquhart by the Geological Survey in the first decade of this century is recorded over the initials of E. H. Cunningham Craig in *The Geology of the Country Round Beauly and Inverness* (Memoir No. 83, 1914). Cunningham Craig's primary conclusion, that an inlier of the Lewisian Gneiss within the Moine Series is exposed in Glen Urquhart, is untenable. This will be demonstrated in the paper on amphibolites and particularly in the study to be published later on the folded structure of the sediments and their subsequent alkali metasomatism. All the crystalline rocks of the glen are thought by the writer to be members of the Moine Assemblage.

The bulk of Cunningham Craig's field observations are however valid. They have been verified fully on the ground. Through the kindness of Dr. T. H. Whitehead and the Staff of the Geological Survey at Edinburgh the 6 in. to 1 mile manuscript map of the area (from which a part of the one-inch Sheet 83 is derived) was examined and copied. The writer's subsequent mapping (Plate 10) is little different from the Geological Survey map in respect of the limestone outcrops.

Finally, the limestones have been described in H.M. Geological Survey Special Reports on Mineral Resources in Great Britain : vol. XXXV, *The Limestones of Scotland* (T. Robertson *et al.*, 1949), and vol. XXXVII, *idem, Chemical Analyses and Petrography* (A. Muir *et al.*, 1956). This contains a petrographic description of a slide of Glen Urquhart limestone, together with a chemical analysis and spectrographic estimation of trace elements in this rock (quoted below).

Field Occurrence

Cunningham Craig (1914) describes the bed as follows :

" The limestone, of which a thickness of 30 or 40 ft. is exposed, is a highly crystalline white marble, with a considerable development of lime-silicates in some of the beds. The purest beds have been quarried and burnt for lime and are still occasionally made use of."

At its largest development in the area of the quarries just north of Upper Gartally Farm the lithological variations within the limestone can clearly be seen. Weathering white or grey the purest bands are always distinguished by a speckling of pale lamellae of phlogopite. Towards the western end of the largest quarry are striped beds which plunge beneath the purer beds at the east. These are banded marbles which break along the mineral banding (which appears to parallel the bedding planes), to form flat, flagstone-like boulders. The bands are alternately pale, relatively pure phlogophite marbles and dark, randomly-crystallized actinolite-diopside rocks, the whole being perhaps a case of metamorphic differentiation. In the northernmost quarry of this group relatively pure marbles carry thin veneers of pyrite on bedding planes.

[1] Doubt has been cast on the status of Heddle's " xantholite " (Francis, 1955) but A. Juurinen (1956) has since shown by chemical analyses of the type material from the Royal Scottish Museum, Edinburgh that the mineral is a true staurolite somewhat rich in MgO, CaO, and H_2O.

In exposures further north (e.g. on Torr Buidhe) light green crystals belonging to the epidote group are prominent, whilst strings and blebs of quartz, elongated with the bedding, are to be seen in all exposures. Actinolitic bands, like those of the Gartally quarries, are found and, like those, they show a haphazard arrangement of lustrous, bottle-green amphibole prisms 1 to 2 cm. in length. On exposed hilltops on Torr Buidhe and west of Loch Maolachain weathering has formed " karst structures " or " grikes ". " Limestone " has occasionally been mapped in the present survey in a few areas in which sedimentary impurity or subsequent metasomatic activity have so diminished its lime content as to prohibit the crystallization of abundant calcite. Thus in the sedimentary inclusion within the serpentinite north-east of Beinn a'Ghairchin a green-white, banded actinolite–diopside–clinozoisite–plagioclase rock is mapped with the limestone. The status of some such rocks must be regarded as uncertain, whilst others may have arisen by the action of lime metasomatism on a pelitic host.

Mineralogy

Calcite. This mineral occurs in all quantities from the main constituent of a rather pure marble, through a stage in which it is the groundmass to amphibole, pyroxene, and mica crystals, to mere interstitial traces. When abundant it forms a simple mosaic, with polyhedral margins (Pl. 8, fig. 1). Crenulate margins are infrequent. The common development of lath-like $(01\bar{1}2)$ twin lamellae as the long diagonal of the rhombs defined by the $(10\bar{1}1)$ cleavages is to be found abundantly in slides of these marbles. The twin lamellae are usually narrow, suggesting that their formation (as glide planes) was not induced by very great deformation. Their orientation, as shown by Tilley (1920), provides a check on the nature of the rhombohedral carbonate. No glide twins forming the short diagonal of the cleavage rhombohedron (e.g. $(02\bar{2}1)$) have been observed, suggesting that dolomite is absent. This inference is supported by the metamorphic facies of the rocks, the place of dolomite being taken by actinolite and diopside. The calcite holds minute flecks of graphite, blebs of quartz and feldspar, and lamellae of phlogopite, even in the purest marbles. Calcite quite frequently occurs in symplectitic intergrowths with other minerals, chiefly plagioclase and zoisite.

Quartz is almost universally present in the limestone either in granular interstitial growth or as strings and blebs within and between the calcite crystals elongated with the bedding, some of it is probably of later introduction into the limestones.

Feldspars. The feldspar of the limestones is, in the great majority of cases, a member of the plagioclase series. It ranges in composition from a rather pure albite to andesine (An_{36}) according to measurements on extinction in twinned crystals sectioned normal to *a*. Crystals up to 1 mm. diameter occur, but they are commonly smaller. Albite and pericline twins predominate. Almost all the plagioclase of the limestone is decomposed. Sometimes large crystals of the epidote group replace the bulk of the feldspars, at other times the alteration has formed a fine-grained saussurite of the same minerals. A fine dust of other minerals such as quartz, apatite, amphibole, and phlogopite is commonly held as inclusions. Plagioclase and zoisite form symplectitic intergrowths.

Microcline has been recognized in a few alkali-injected marbles close to granite pegmatites. The characteristic grid twinning and a yellow stain with potassium cobaltinitrite after etching with HF confirm this identification.

Zoisite. This mineral is common, particularly in association with plagioclase. Both the alpha and the beta forms occur, and their optics always agree with those quoted in the standard texts (e.g. Winchell, 1951 : 446–447). One remarkable crystal possesses a core of α-zoisite with the optic plane parallel to (010), and $2V\gamma = 56°$. Dispersion, r>v, is strong, and there is anomalous blue birefringence. An incomplete rim is developed in which the optic axial plane is normal to (010) and $2V\gamma = 7°$ (both angles measured on the universal stage in white light). The dispersion in the rim is r<v, distinct, and the birefringence produces greys of the first order (Text-fig. 1).
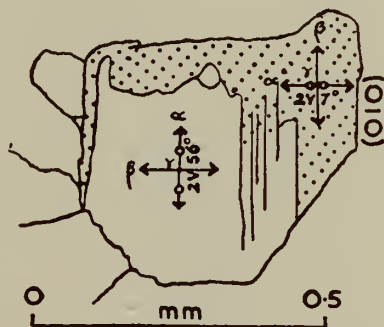

FIG. 1. Zoisite crystal containing the α and β forms, from the limestone quarry north of Beinn a' Ghairchin.

These groundmass zoisites may increase in amount to become the most abundant mineral in the rock. Such specimens may be found in the quarries between the buildings of Upper Gartally Farm. Occasionally prismatic, the zoisites are commonly xenoblastic and ragged in their outlines towards the quartz and calcite which accompany them. They grow to several centimetres in length and millimetres in width. Birefringence is low, being predominantly in greys, whilst vivid, anomalous " ultra-blues " occur patchily within the crystals. Cleavage parallel to (010) is well developed. The crystals are commonly sieved with inclusions of quartz and amphiboles. Veins of pink β-zoisite in injected limestone probably belong to the variety thulite.

Some of the zoisite-rich rocks (e.g. around Upper Gartally) may represent impure limestones, but a further increase in zoisite in the same area leads to massive, cavernous, monomineralic zoisite rocks which cannot be regarded as metamorphosed sediments. They must be grouped with the calc-silicate skarns to be described in Part II of this work.

Clinozoisite and epidote. These minerals, though less abundant than the zoisite, are quite common in the limestones. They may occur in separate rocks, or together in the same rock. In the latter case they are usually found in crystals

zoned from clinozoisite cores to epidote rims. Beautiful examples of zoning may be found, picked out between crossed nicols by variations in their bright second-order interference colours. Compositions of these minerals are most readily determined in sections cut normal to the b axis of individuals twinned on (100), in which the diagnostic extinction angle $\alpha \wedge c$ can be measured to the twin plane. No β-clinozoisite (Johnston, 1949) has been found.

Text-fig. 2 shows a clinozoisite–epidote individual from an impure limestone band. It is truncated by a larger clinozoisite–epidote. Johnston (1949) and Winchell (1951) show that clinozoisite has its α-vibration direction in the obtuse angle β, whilst epidote has its α-vibration direction in the acute angle (supplementary to β). Thus the negative extinctions in Text-fig. 2 are in α-clinozoisite, the positive extinctions in epidote. Further, oscillatory zoning is present. There is a narrow core of clinozoisite, a wider irregular series of epidote zones and a final wide clinozoisite rim. This is the only measured crystal in which a clinozoisite rim has been found.

FIG. 2. Twinned clinozoisite–epidote crystal, from impure limestone in the block of schists within the serpentinite 300 m. west of Loch Maolachain. The extinction angles of the numbered zones are : 1, $\alpha \wedge c - 2°$; 2, $\alpha \wedge c$; $+ 4°$; 3, $\alpha \wedge c - 3°$; 4, $\alpha \wedge c - 1°$; 5, $\alpha \wedge c - 2°$; 6, $\alpha \wedge c + 3°$; 7, $\alpha \wedge c + 6°$; 8, $\alpha \wedge c + 10°$; 9, $\alpha \wedge c - 2°$.

Very similar clinozoisite–epidote crystals are prominent in the skarns to be described in Part II. Clinozoisite–epidotes in the limestones vary from saussuritic material up to crystals 1 to 2 mm. in length. They are almost always in close association with plagioclase.

Amphiboles. The amphiboles of the limestones apparently belong to three transitional types. Actinolite, tremolite, and " edenite ". The same three types recur in the skarns. Heddle (1901, Vol. II) gives three amphibole analyses from Glen Urquhart, and three more have been carried out for this study. Of these, the three new analyses and perhaps two of Heddle's belong to the skarns (he did not differentiate skarns from limestones in his study of the Gartally localities). Heddle's remaining analysis is of a high-silica tremolite (Text-fig. 8) ; it has indeed, more silica than any in Hallimond's survey of the calciferous amphiboles (1943), containing

in fact Si slightly in excess of the 8 atoms required for pure tremolite and lacking Al in the Z group ; the possibility of some impurity or analytical inaccuracy or both cannot be discounted in an early analysis such as this one. Nevertheless, it is clearly one of the high-silica calciferous amphiboles and plots in Hallimond's diagram along with the amphiboles of metamorphic limestones. The remaining five amphiboles from Glen Urquhart plot in the field of " schists " in Hallimond's diagram, in which group we may (for this purpose) allow skarns a place (Text-fig. 8).

In the limestones pale to bottle-green prismatic amphiboles of late " spearing " growth have been distinguished as actinolite, almost colourless prisms as tremolite and occasional fibrous nests of green, fasciculitic or plumose amphibole as hornblende. The use of the word " edenite " for these amphiboles is discussed in Part II. These are field terms, supported only by the optical data given in Table I. Chemical analyses of the amphiboles of the limestones proper at Glen Urquhart are still required.

TABLE I.—*Optics of Amphiboles from Limestone*

	Actinolite	Tremolite	Hornblende
Pleochroism :			
α	colourless .	colourless .	colourless
β	grass green .	pale straw .	,,
γ	jade green .	pale grass green .	pale straw
Extinction :			
($\gamma \wedge c$)	16°–18° .	18°–20° .	21°–23°
Optic Axial Angle :			
($2V_\alpha$)	81° average .	83° average .	84° average
Refr. Index : β			
in sodium light ($\pm$ ·002) .	1·634 .	1·623 .	1·623

Pyroxenes. The limestone pyroxenes are closely similar to those of the skarns, which, as shown in Part II, are diopside and salite. Salite predominates in the limestone. The size may vary widely from small idioblasts of 0.2×0.7 mm. to large equant crystals 4 mm. across. There is a strong tendency to form crystal outlines especially towards calcite, although irregular growth may occur.

Micas. Pale phlogopite crystals are common in the limestone. They are usually small, averaging (0·5 mm. diameter), but may form large plates up to 3 mm. across. Pleochroic haloes about sphene and zircon grains have been found. The pleochroism scheme is γ and β pale brown, α colourless. The interference figure is normally uniaxial, sometimes a small optic axial angle may be observed. Cleavage flakes from parageneses 8, 9 and 11 (Table II) examined in sodium light, gave a uniform refractive index of 1·587 ($\pm$ ·002) indicating phlogopite with Mg″ : Fe″ : 90 : 10 (Winchell, 1951).

Muscovite flakes occur in limestones affected by alkali injection from nearby granite pegmatites.

Accessories. Sphene is almost universal in the limestones. Graphite is a common

accessory, and pyrite (with some pyrrhotite) is a frequent associate. Apatite. zircon, and magnetite also occur.

Petrology. Parageneses recorded in the Glen Urquhart limestones are given in Table II, below. Limestones which have been affected by injection from neighbouring granite pegmatites are listed separately.

TABLE II.—*Limestone Parageneses*

1 ct-qtz-zo-trem-di
2 ct-qtz-zo-plag(An_{36})-act-di
3 ct-qtz-zo-plag(An_{33})-act-di-phlog
4 ct-qtz-zo-plag-hb
5 ct-qtz-zo-plag(An_{14})-phlog
6 ct-qtz-zo-phlog
7 ct-qtz-clz/ep-act
8 ct-qtz-clz-plag(An_{33})-act-di-phlog
9 ct-qtz-clz-di-phlog
10 ct-qtz-ep-plag (and)-act·phlog
11 ct-qtz-plag (and-hb·phlog
12 ct-qtz-plag(An_{18-30})-act-di
13 ct-qtz-plag-act-di-phlog
14 ct-qtz-plag(An_5) phlog
15 ct-zo-plag(olig.)-hb-di
16 ct-clz/ep-plag(An_{15})-act-phlog
17 ct-hb-phlog
18 qtz·zo-trem
19 qtz-zo-trem-di

Injected limestone Parageneses

20 ct-qtz-zo-plag(olig)-mu-phlog
21 ct-qtz-ep-plag(olig)-mu-phlog
22 ct-phlog-qtz-(chl)
23 ct-qtz-mic-mu-phlog-(chl-tourm)

Accessories : sphene, graphite, pyrite, pyrrhotite, apatite, zircon, magnetite.
Abbreviations : act, actinolite ; and, andesine ; an, anorthite ; chl, chlorite ; clz, clinozoisite ; ct. calcite ; di, diopside ; ep, epidote ; hb, honblende ; mic, microline ; mu, muscovite ; olig, oligoclase ; phlog, phlogopite ; plag, palgioclase ; qtz, quartz ; tourm, tourmaline ; trem, tremolite ; zo, zoisite.

Photomicrographs. Four thin sections from the limestones, illustrating parageneses 11, 14, 18, and 19, appear in Pl. 8, with annexed descriptions.

Chemical Composition

An analysis with spectrographic determination of the trace elements (see Table III), and a petrographical description of a Glen Urquhart limestone specimen are given in Muir *et al.* (1956). The analysis and description make it clear that it is a rock rich in calcite and poor in calc-silicates. This relatively pure limestone is naturally the rock of interest in an economic study of this kind. The bulk of the Glen Urquhart limestones are, however, less pure, containing phlogopite "epidote"[1]

[1] By "epidote" is here implied a member of the group: zoisite, clinozoisite, and epidote.

diopside and tremolite in some quantity. The two latter minerals, with high magnesia contents, must raise the Mg/Ca ratio of the impure beds above that of the analysed limestone, and this suggests that the original formation was partly dolomitic. Alumina, which must also be higher in the impure beds, suggests argillaceous material, and the sediment, as a whole, was therefore in all probability a somewhat muddy, siliceous, dolomitic limestone.

TABLE III.—*Limestone, Glen Urquhart*

(Containing phlogopite and calc-silicates, [Muir *et al.*, 1956])

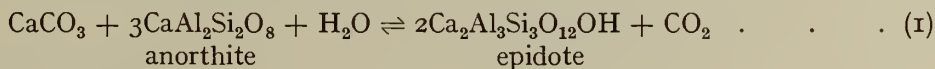|	1		2
SiO_2	9·49	Ga	*
Al_2O_3	1·40	Cr	5
FeO	0·82	V	*
FeO	—	Su	*
MgO	2·23	Li	3
CaO	47·86	Ni	*
Na_2O	0·24	Co	*
K_2O	0·36	Zr	50
$H_2O-105°$	0·07	Y	*
TiO_2	0·09	La	*
P_2O_5	0·03	Sr	300
MnO	0·01	Pb	*
CO_2	37·36	Ba	20
FeS_2	0·08	Rb	*
	100·04		

Sp. Gr. . 2·73

1 Percentage weight of oxides. *Analysts*, A. Muir and H. G. Hardie.
2 Trace elements, parts per million by weight. Spectroscopist, R. L. Mitchell.
* Present, but below the limit for quantitative determination of this element (see Mitchell *in* Muir *et al.*, 1956).

Metamorphic facies. The above parageneses suggest crystallization within the lower part of the amphibolite facies. Ramberg has shown the importance of the association of plagioclase with the epidote minerals from the viewpoint of the facies classification (e.g. 1952 : 50–54). He defines the lower limit of the amphibolite facies by the association " epidote "—An_{30} in most rocks. Higher anorthite contents in association with epidote minerals occur at successively higher $P–T$ conditions (grades).

In the Glen Urquhart marbles andesine (to An_{36}) is commonly found in association with an epidote mineral in rocks showing no evidence of disequilibrium at the time the pair crystallized. This $P–T$-sensitive association may possibly be disturbed in calcite-rich environments by reactions tending to " leach " anorthite out of plagioclase, even at high temperature, e.g.:
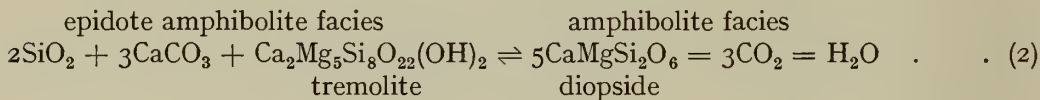
$$CaCO_3 + 3CaAl_2Si_2O_8 + H_2O \rightleftharpoons 2Ca_2Al_3Si_3O_{12}OH + CO_2 \qquad . \qquad . \qquad . \quad (1)$$
$$\text{anorthite} \qquad\qquad\qquad \text{epidote}$$

(Ramberg, 1952 : 150).

One of the calcite-rich rocks (paragenesis 14) in this study contains an anorthite-poor plagioclase (An_5), but this does not give evidence of anorthite "leaching" since an epidote mineral is lacking. In the absence of "epidote" the plagioclase composition at a given grade may vary from the composition crystallizing with an epidote mineral to pure albite; the anorthite content of the plagioclase here depends solely on the original composition of the rock. It seems, indeed, as if this "leaching" of the anorthite content of plagioclases has not occurred in the Glen Urquhart marbles since plagioclase in association with "epidote" is not restricted to compositions close to albite. The association andesine-"epidote", therefore is not ambiguous, and suggests the lower part of the amphibolite facies for the crystallization conditions of these rocks.
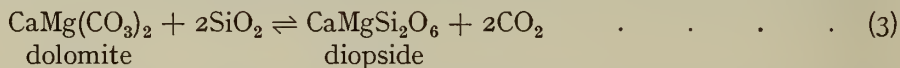
Ramberg (1952 : 150) also states that "another indication of the amphibolite $\rightleftharpoons$ epidote amphibolite facies transition is the lowermost stability border of diopside in calcite milieu.

"The following reaction :

epidote amphibolite facies   amphibolite facies

$$2SiO_2 + 3CaCO_3 + Ca_2Mg_5Si_8O_{22}(OH)_2 \rightleftharpoons 5CaMgSi_2O_6 = 3CO_2 = H_2O \quad . \quad . \ (2)$$
$$\text{tremolite} \qquad \qquad \text{diopside}$$

referring to the pure Mg-silicate end-members of the mixed crystals, may be the proper indicator of the lowermost border line of the amphibolite facies".

Weeks in his recent study of the metamorphism of siliceous carbonate rocks (1956) has shown that diopside is the third mineral to appear in progressive "equilibrium" metamorphism of a siliceous dolomite (talc and tremolite are the first and second, respectively). The temperatures at varying pressures for the calculated curve of the reaction :

$$CaMg(CO_3)_2 + 2SiO_2 \rightleftharpoons CaMgSi_2O_6 + 2CO_2 \qquad . \qquad . \qquad . \qquad . \ (3)$$
$$\text{dolomite} \qquad \qquad \text{diopside}$$

lie within the lower part of the amphibolite facies (Weeks, 1956, fig. 4, and p. 265, footnote).

Weeks has used reaction (3) rather than reaction (2) (of the present paper) since thermochemical data on tremolite were not published at the time he wrote his paper. It is probable that diopside crystallized by a process of the type of reaction (2) at Glen Urquhart as dolomite will already have been eliminated in the production of tremolite in rising metamorphism. There is no textural evidence for reaction (2) running from left to right. Much of the amphibole in the marbles is in late "spearing" prisms or needles, cutting right through diopside crystals. Such amphiboles cannot be "parental" to the diopsides. They probably indicate a retrograde displacement of reaction (2) towards the left. "Parental" tremolite may exist in the less common xenoblastic grains associated with diopside, but clear textual evidence has not been found.

In some fields diopside and tremolite minerals appear to have crystallized at equilibrium. Bowen (1940) has shown that in progressive metamorphism of siliceous
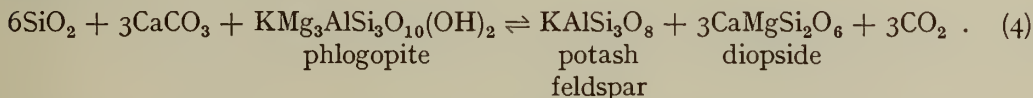
dolomites there is a stage at which this pair may be expected to co-exist at equilibrium.

To summarize, it seems clear that the Glen Urquhart limestones have crystallized just within the lower grade limits of the amphibolite facies. The adjacent isograde kyanite schists have been assigned, partly with reference to diopside in these marbles, partly on independent evidence, to a similar position in the amphibolite facies (Francis, 1956b).

Low amphibolite facies associations in marbles. Turner (1948) and Ramberg (1952) have considered problems bearing on calcite–biotite (phlogopite) relationships in the amphibolite facies. Turner states (p. 84) that the " occurrence of potash feldspar as a minor constituent of calc-schists and marbles . . . is very general " and " the appearance of microcline in an environment of calcite and calc-silicates is due in the main to the chemical composition of the rock rather than to its physical properties, for, in all but highly magnesian rocks, potash feldspar will always crystallize in preference to mica if the ratio

$$\frac{CaO + K_2O + Na_2O}{Al_2O_3}$$

exceeds unity ". Ramberg, on the other hand, remarks (p. 152) that " it is common to find biotite or, rather, phlogopite as apparently stable mineral grains in amphibolite facies marbles ". He concludes by means of an ACF[1] + silica tetrahedron that the association calcite–phlogopite is only stabilized in the absence of excess silica (quartz) according to the reaction :

$$6SiO_2 + 3CaCO_3 + KMg_3AlSi_3O_{10}(OH)_2 \rightleftharpoons KAlSi_3O_8 + 3CaMgSi_2O_6 + 3CO_2 \quad . \quad (4)$$

phlogopite   potash   diopside
                        feldspar

He comments that " the placing of calcite or dolomite in ACF diagrams easily causes misunderstanding and confusion. The equilibrium relationships between the carbonates and the several principal silicates need at least a tetrahedron diagram to be visualized ". This is true but, as will be seen, the best tetrahedron is not bounded by A, C, F, silica, but by A, C, F, K.

Turner has foreshadowed this by suggesting (1948 : 81–82) that the ACF diagram for the amphibolite facies should be interpreted in conjunction with the AKF diagram. To take up this suggestion the ACFK tetrahedron is necessary, but there is at first a small alteration to be made. " A " of the ACF diagram is not the same as " A " of the AKF diagram (Turner, 1948). For the purpose of the ACFK tetrahedron " A " should be calculated as molecular Al_2O_3 in excess of molecular $Na_2O + K_2O$ only. CaO is excluded from the calculation, and the resulting " A " is similar to that of the ACF diagram.

As we have seen, Turner and Ramberg both imply that marbles will hold either microcline or biotite (phlogopite) at equilibrium but not both together. Turner believes that the choice is determined by whether or not the rock is highly magnesian, and that microcline is the commoner mineral. Ramberg believes that the choice

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[1] ACF and AKF diagrams, introduced by Eskola, are defined in Turner (1948 : 57 and 82).

is determined by the presence or absence of excess silica (quartz) and that phlogopite is the commoner mineral.

A study of the ACFK tetrahedron (which is constructed for rocks with excess silica provides an alternative answer to the problem and shows, incidentally, that the associations calcite–microcline–phlogopite and calcite–quartz–phlogopite in marbles and skarns are possible at equilibrium in the lowest part of the amphibolite facies (see also Table II for observed cases of these associations).

The ACFK tetrahedron can first be visualized in terms of its faces. The ACF and AKF faces are given, e.g., by Turner (1948, figs. 19, 20)[1] the remaining two, the ACK and the FCK are shown in Text-figs. 3 and 4. The ACFK tetrahedron is shown in Text-fig. 5. In this diagram the field of limestones and skarns, with the appropriate minerals is picked out.
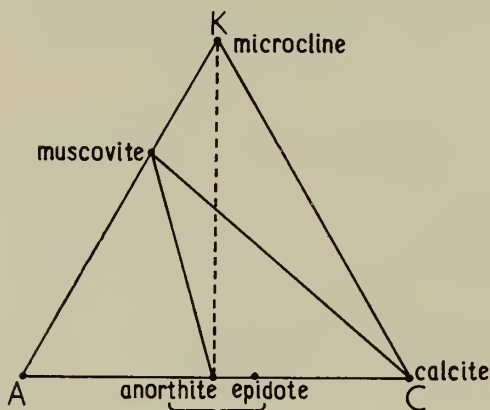

FIG. 3.

FIG. 4.

FIG. 3. The ACK triangle for rocks with excess silica in the lower part of the amphibolite facies.
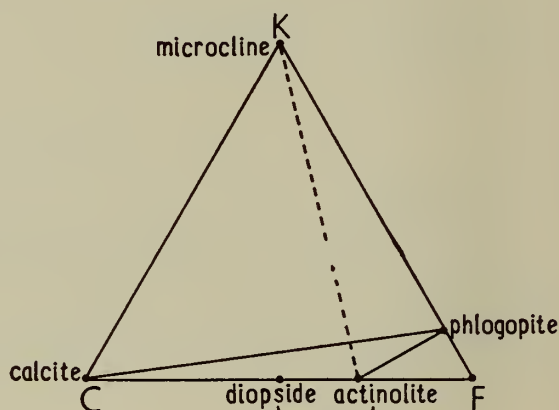
FIG. 4. The FCK triangle for rocks with excess silica in the lower part of the amphibolite facies.

In these diagrams there are two pairs of minerals each of which may be pictured as a " single " phase for the purpose of the diagrams, provided their true status is understood. The pairs are plagioclase and " epidote ", diopside and actinolite. These typical members of impure limestone parageneses involve two components in excess of the four plottable components of the ACFK tetrahedron, namely Na_2O and H_2O. In effect plagioclase, " epidote " and actinolite all lie outside the ACFK plot, in the direction of the Na_2O or H_2O components. From phase rule considerations we may thus have two extra phases (minerals) at equilibrium in the system,

[1] Turner (1948 : 79, and figs. 18 and 19) has suggested that in ACF diagrams for potash-deficient rocks in his cordierite–anthophyllite and staurolite–kyanite subfacies the limestone field should be left as a vacant field, " since the total potash in all rocks sufficiently rich in lime and poor in alumina to fall within this area is held in potash feldspar ". The theoretical and observed parageneses discussed in this paper show, however that assemblages free from potash feldspar of this metamorphic grade exist in the limestone field, which is not, therefore, vacant.

i.e. six plus quartz instead of four plus quartz (cf. parageneses of Table II). The relationships between plagioclase and " epidote " and between diopside and actinolite have been considered above.[1] Muscovite and biotite are also, of course, projections into the ACFK plot from a system containing water, but they have no corresponding anhydrous minerals to pair with as have " epidote " (anorthite) and actinolite (diopside).
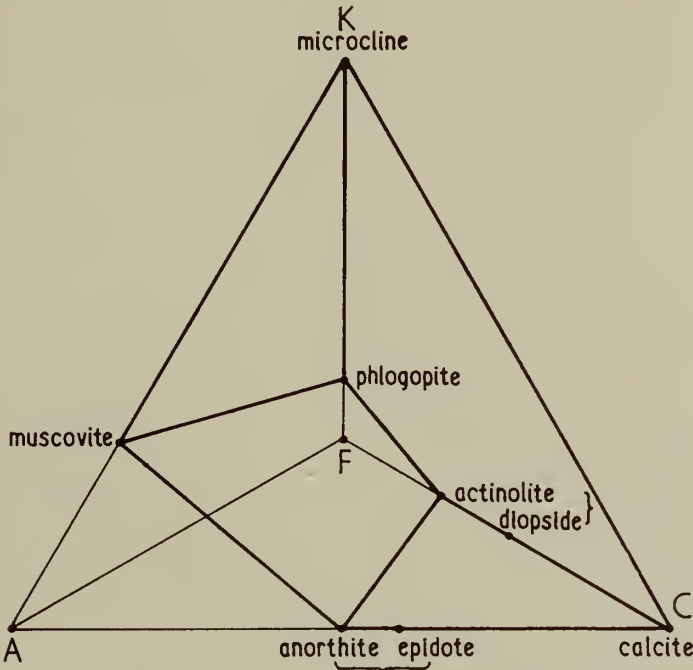
FIG. 5. The ACFK tetrahedron for rocks with excess silica in the lower part of the amphibolite facies.

The field of limestones and skarns in the ACF diagram involves the three phases : ct-" an "-" di ". The same field in the ACK diagram (Text-fig. 3) and the FCK diagram (Text-fig 4) is in each case a quadrilateral, which can, for phase rule purposes, be split into two triangular fields. Moreover, in each plot there are two possible ways of dividing the appropriate quadrilateral, indicating that the alternative parageneses are in *crossed relationship*. Thus, in the ACK diagram the quadrilateral is : ct-" an "-mu-mic, which can be divided according to *Stability A* into [ct-" an "-mu] and [ct-mic-mu] by the two-phase join ct-mu, or according to *Stability B* into [ct-" an "-mic] and [" an"-mu-mic] by the join " an "-mic. Similarly, for the FCK diagram the quadrilateral is ct-" di "-phlog-mic, which can be divided

[1] For the purpose of representing theoretical assemblages in this discussion " an " is used to represent plagioclase or " epidote " or both, " di " is used to represent diopside or a calciferous amphibole or both. The remaining minerals are represented by the abbreviations of Table II.

according to *Stability A* into ⌊ct-phlog-mic] and [" di "-phlog-mic] by the join ct-phlog, or according to *Stability B into* [ct-" di "-mic] and [" di "-phlog-mic] by the join " di "-mic.

These considerations applied to the more complex case of the ACFK tetrahedron show that the complete limestone-skarn field is an irregular triangular prism ct-" an "-mu-phlog-" di "-mic (Text-fig. 5). This may be split initially into a tetrahedron, and a quadrilateral pyramid by a three-phase plane. The quadrilateral pyramid may then be split into two tetrahedra by a second three-phase plane in one of two possible ways.

It thus appears that by means of two three-phase planes the initial irregular triangular prism may be split into three tetrahedra.[1] By inspection it can be seen that there are six of these potential three-phase planes in the irregular triangular prism, namely,

$$A : ct\text{-}mu\text{-}phlog$$
$$B : mic\text{-}"\,di\,"\text{-}"\,an\,"$$
$$C : ct\text{-}phlog\text{-}"\,an\,"$$
$$D : ct\text{-}"\,di\,"\text{-}mu$$
$$E : mu\text{-}"\,di\,"\text{-}mic$$
$$F : phlog\text{-}"\,an\,"\text{-}mic,$$

and that there are, in all, six possible sets, each of three tetrahedra (or six pairs of three-phase planes).

It may be noted that the three-phase plane A and the three-phase plane B are in crossed relationship and correspond to the two-phase joins in crossed relationship in the ACK and FCK triangles.

In the Glen Urquhart limestones there are three four-phase assemblages together with three three-phase, and two two-phase assemblages. The whole group can be shown to be at equilibrium under conditions where the limestone-skarn prism is subdivided by the three-phase planes A and C (and not by any of the others). The arrangement of the subdivided prism is shown in exploded form in Text-fig. 6 and the theoretical and observed assemblages appear in Table IV below.

TABLE IV.—*Equilibrium Limestone Assemblages*

Theoretical (+ qtz)		Observed (Table II)
ct-phlog	.	22
" an "-" di "	.	18, 19
ct-" an "-phlog	.	5, 6, 14
ct-" di "-phlog	.	17
ct-" an "-" di "	.	1, 2, 4, 7, 12, 15
ct-" an "-" di "-phlog	.	3, 8, 9, 10, 11, 13, 16
ct-" an "-mu-phlog	.	20, 21
ct-mic-mu-phlog	.	23

[1] The phase rule allows a maximum of four phases (i.e. a tetrahedral stability field) in this four-component (ACFK) system. We have already seen that there are three unplottable additional components playing a less important role in the full system, namely excess SiO_2 in quartz (which is always present), Na_2O in plagioclase, and H_2O in " epidote ", actinolite, and the micas, thus permitting the crystallization of three additional phases (minerals) at equilibrium.

Microcline and muscovite are only represented in the limestones affected by alkali injection near to granite pegmatites. These injected limestones carry some (? retrograde) chlorite after phlogopite and occasionally some tourmaline. Such rocks occur at Torr Buidhe, at the northernmost limestone quarry in the area, and at the quarry above Kilmichael Church. The other parageneses are distributed evenly through the limestone outcrops.
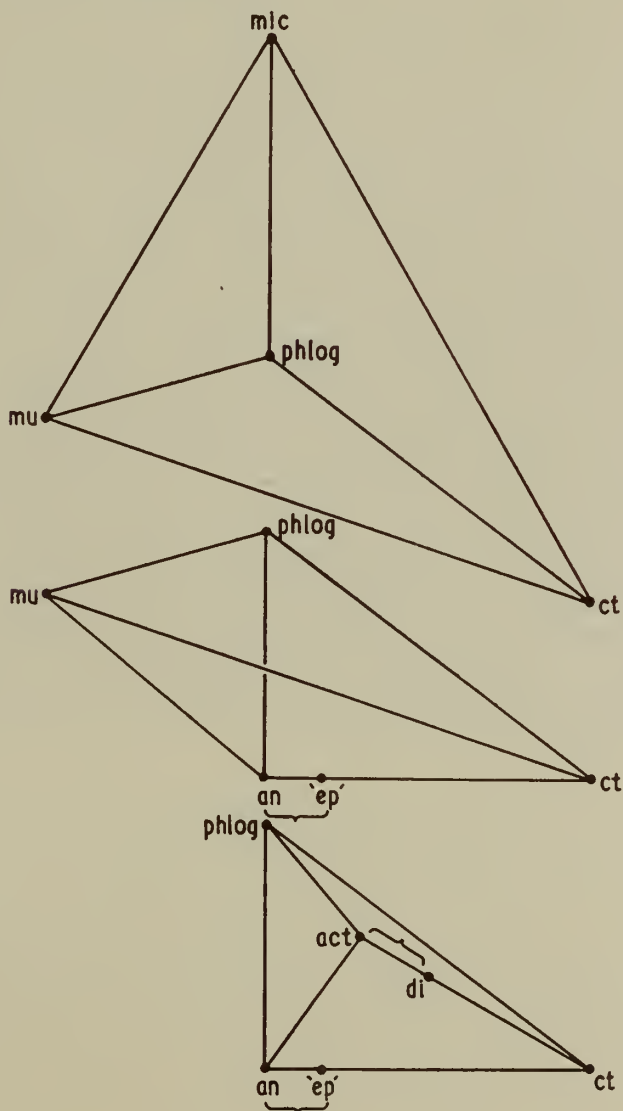

FIG. 6. Three four-phase fields delimited by the planes ct-mu-phlog and ct-phlog-" an " in the ACFK tetrahedron, illustrating the parageneses of the Glen Urquhart limestones.

The biotite of the marbles is highly magnesian, and is stable with diopside (and amphiboles) and quartz. Ramberg's reaction (No. (4) of this paper) does not therefore seem to have taken place. The high Mg″/Fe″ ratio of the mica apparently reflects a similar ratio in the parent rock (dolomitic limestone).[1] The reasons for this common condition in the parent rock are chemical factors during its sedimentation or subsequent diagenic alteration. The origin of the high Mg″/Fe″ of many limestone biotites can therefore be traced back to the geochemistry of some particular sedimentary or diagenic process rather than to reactions within the amphibolite facies.

Systematic absences. Dolomite and talc are absent from the parageneses at Glen Urquhart, presumably having been resorbed before the appearance of diopside, the third mineral in the progressive metamorphism of a siliceous dolomite rock. Wollastonite is absent and quartz plus calcite is the universally stable alternative. The temperature attained cannot have been sufficient to stabilize wollastonite under the pressures on the solid and the fluid phases ruling during the metamorphism of this limestone. Idocrase and grossular are absent and may well represent higher grade conditions within the amphibolite facies than those that operated at Glen Urquhart (Ramberg, 1952). Weeks (1956) has recently calculated that forsterite should appear at higher grade than diopside. He has also suggested why enstatite does not occur in metamorphosed siliceous dolomites. These minerals therefore need not be expected in the Glen Urquhart limestones.

Summary. The metamorphosed siliceous magnesian limestones of Glen Urquhart were crystallized at equilibrium just within the lower stability limit of the amphibolite facies. All the minerals to be expected in limestones at this metamorphic grade are present, and some of their characteristics have been described. There are other minerals whose compositions fall within the same chemical field but whose absence may be explained on physico-chemical grounds. The assemblages calcite–microcline–phlogopite and calcite–quartz–phlogopite are both shown to be stable in theoretical and observed parageneses. It is demonstrated that there is no vacant space in the limestone field of the ACF diagram for rocks deficient in potash (lacking potash feldspar) at this metamorphic grade.

PART II

SKARNS

Previous Work

The calc-silicate skarns mentioned in the Introduction to this *Bulletin* have not previously been studied as a separate rock group in Glen Urquhart. It is clear from the writing of previous workers (particularly Cunningham Craig) that these rocks were regarded as impurities interbedded with and stratigraphically succeeding the limestones. The evidence, presented below seems clearly to indicate that the rocks, at the boundary between the limestone and the kyanite schist, are the products of metasomatism, rather than of changing sedimentation. Many of the silicate

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[1] i.e. the normally high Mg″/Fe″ ratio in impure limestone, or, put another way the more frequent occurrence of dolomitic rather than ankeritic limestone.

minerals from Glen Urquhart analysed by Heddle can fairly be assumed to come from these skarns rather than from the limestones proper.

Field Occurrence

The mode of occurrence of the calc-silicate rocks has been mentioned briefly in the Introduction. Lying between calcareous and aluminous rocks, and accompanied by much quartz veining they at once appear to be the products of chemical mingling between two unlike sedimentary formations in contact. This impression is confirmed by the chemistry of the skarns which will be shown to be intermediate between that of the limestone and that of the kyanite schist. It is also confirmed by the evidence of transported material in the skarn zone, lime, for example, in quartz veins containing calcite and calc-silicates, and alumina in kyanite-bearing quartz veins. Metasomatism is demonstrated in mono- and bi-mineralic silicate rocks, chemically distinct from calcareous or aluminous sediments, often arranged in convoluted zones, unrelated to the still-recognizable folded bedding-planes of the adjacent sedimentary rock. Metasomatism is, indeed, most clearly indicated under the microscope, where replacement of original minerals by others, leading to enrichment of a kyanite schist host-rock in lime and a limestone host-rock in alumina (and silica), can clearly be followed in successive stages.

The interaction of two chemically dissimilar rock masses in contact with one another, under the influence of volatiles and of raised temperature, is to be expected. This chemical reaction must lead to a diminution of the chemical potential (free energy) in the rocks at the contact. It is a case of *reaction skarn* formation in the extended meaning of the word skarn (Holmes, 1920). Although granite is not directly concerned at the site of the skarns (as is usually the case) the quartz veins are clearly linked to granite pegmatites and granite-like rocks exposed at no more than a few hundred metres from the skarn zones.

The skarns may be considered in three main groups: epidosites, epidote-hornblende skarns, and plagioclase skarns; pale-amphibole skarns; prehnite and pectolite skarns.

Group I : Epidosites, Epidote-Hornblende Skarns and Plagioclase Skarns

Pure epidote rock is subordinate, but good examples of this rock, epidosite,[1] can be found at the Gartally quarries, Torr Buidhe, and elsewhere, associated with the more abundant epidote–hornblende skarns. Fine specimens of zoisite rock can be found amongst the Gartally quarries. From one of these a cavernous aggregate of intergrown zoisite prisms up to 3 cm. × 8 cm. has been obtained. The cavernous nature of some of these zoisite rocks is in contrast with the compact and strongly lineated crystallization of some of the other skarns, notably those built of pale amphiboles. Differences in the physical conditions at various sites and probably slight differences in age are betrayed by these contrasting crystallizations. On

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[1] In spite of the objections to the use of this term raised by Flawn (1951), it is here retained. " Epidosite " has always been preferred to the alternative " epidotite " in the literature on the Highlands (e.g. Flett, 1906; Flett, *in* Hinxman *et al.*, 1913 : 50; Harker, 1939 : 268, Bailey, 1955 : 133). Retention of the former term in a work on Highland rocks appears simpler, and preferable to the use of the variant.

Torr Buidhe fine-grained apple-green rocks composed of clinozoisite–epidote have been collected along with quartz veins enclosing abundant clinozoisite, rimmed with epidote. These veins grow to a pegmatitic grain size. One vein contains clinozoisite, idioblastic to a fine-grained mosaic of quartz, in prisms up to 2 cm. diameter. More frequently the quartz–epidote mosaic is equigranular, the grains averaging 1 mm. diameter. The clinozoisite is often well crystallized, with good terminations, but these faces proved somewhat too roughened for goniometric work. The crystals may be apple-green, grey-violet or brown in colour.

Associated with the epidosites, and sometimes by themselves, are rocks containing dark green prismatic amphiboles, paler green diopside (salite), and sometimes calcite, quartz, and feldspar. The majority contain " epidote "[1] in varying quantity, some contain none. Again crystallization may be very coarse-grained ; a hornblende–quartz–calcite rock on Torr Buidhe containing amphibole prisms 6 cm. × 1 cm. and a diopside–hornblende–clinozoisite–prehnite rock on Sgòr Gaoitne with diopsides up to 3 cm. × 1·5 cm. are known. Torr Buidhe is a prominent locality for these skarns, and they are also to be found at the following places : Sgòr Gaoithe ; the serpentinite contact due north of the Gartally quarries ; Upper and Lower Gartally farms ; Wester Balnagrantach ; Allt Gartally (at the serpentinite contact) and at the limestone quarry above Kilmichael Church. The host rock can sometimes be shown to be the kyanite schist but the limestone is always close at hand.

The epidosites and the epidote–hornblende skarns are transitional to a group of metasomatic rocks that form along the margins of the serpentinite mass and of which the conspicuous feature is the formation of large plagioclase crystals. Sometimes they coalesce to form plagioclase rocks similar in appearance, though not identical in mode of formation, to the albitites emplaced during the same metasomatic episode into zoned hydrothermal bodies within the serpentinite (Francis, 1955). The normal aspect of the plagioclase rocks in the sediments is one of strong crystalloblastic growth in their host-rock which is kyanite schist (Text-fig. 9). Along with the big plagioclases the calc-silicates " epidote ", hornblende, and diopside play an important part in these rocks. These minerals and the clear participation of Ca-bearing fluids in their genesis (to be described below) perhaps allow these rocks to be classed as *plagioclase skarns*, lying in an extension to the commonly defined limits of skarn composition. The plagioclase skarns occur at Sgòr Gaoithe and at a few other points north-east of that hill, all lying close to the serpentinite contact.

Group II : Pale-Amphibole Skarns

These skarns are quite distinct in appearance and in location on the contacts of limestone with kyanite schist from those of the preceding group. The fact that they both occur at such contacts and that there are mineral similarities between the two groups suggest that their mode of formation and age are similar.

The typical rock is almost monomineralic, and on freshly-broken surfaces shows

[1] See Footnote, p. 130.

sparkling cleavage faces of the amphibole, of a greenish-grey colour ; occasionally a waxy-white diopside of slightly earlier formation occurs with the amphibole, and both minerals will be shown to possess high Mg/Fe″ ratios. The pale-amphibole skarns weather to a pale grey colour and display a furrowed and corded surface. The latter marks out a strong foliation, with a closely-aligned lineation thereon. Folds in this foliation parallel those in the adjacent sediments, but it is not clear whether these folds in the skarn are a palimpsest of the folding of the replaced sedimentary host-rock or whether they have been generated by expansion during the metasomatic replacement itself (cf. Poldervaart, 1953). The host-rock of the pale-amphibole skarns may largely have been limestone. Indeed limestone may play the host's part in this group to a greater extent than in any of the other skarn groups in the Glen (kyanite schist being the resting place of the products of inter-mingling in most cases). Towards the (structural) top of the pale-amphibole skarn masses there is microscopical evidence of a certain amount of kyanite schist host-rock ; anthophyllite has been found as an intermediate product in the formation of the latter skarns.

Pale-amphibole skarns occur in an anticlinal belt north-west of Loch an Sgòr Gaoithe ; in hillocks between Upper Gartally and the limestone quarries, and in the valleys of the stream north-west of Lochan an Torra Bhuidhe and of the Gartally Burn above Milton.

Group III : Prehnite and Pectolite Skarns

This final group forms a very small part of the skarn assemblage. It is closely linked to the first group of skarns and occurs close to them. Like the plagioclase skarns, rocks of this group are restricted to the vicinity of the serpentinite contact. They are found in two places : a few metres west of a number of thin, isoclinally folded outcrops of marble, near the serpentinite, north of Gartally quarries ; and at a few centimetres from the serpentinite contact at Sgòr Gaoithe. The host rock of these skarns appears in every case to have been kyanite schist, although limestone is demonstrably close to them at the former locality and is probably close to them at the latter. The margin of the relatively impervious serpentinite must have determined the location of these skarns as much as the sedimentary junction between kyanite schist and limestone. They are often quite inconspicuous rocks in the field, having much of the appearance of normal kyanite schist. Pseudomorphs in musco-vite after kyanite have been found at an early stage in the alterations. They stand proud from the rock on weathered surfaces. Kyanite relics within them have been converted into clinozoisite (this alteration is discussed below). At a slightly later stage a pale, weathered crust develops and then hydrobiotite, derived from original biotite becomes conspicuous as pale brown or pearly flakes, giving the rock a spangled appearance. In one much altered rock xenoblastic garnets up to 6 cm. diameter occur sporadically. They are intergrown and invested with coarse hydro-biotite plates and white prehnite. Prehnite and pectolite in white, interstitial masses and veins (together with vermiculite) characterize the much-altered rocks quartz and feldspar are eliminated. These rocks bear the imprint of strong lime

metasomatism. For complexity and interest they are not matched by any of the other Glen Urquhart skarns.

Mineralogy

Zoisite and thulite. The cavernous growths of large zoisite crystals at the Gartally quarries have already been mentioned. Here and elsewhere among the epidosites, epidote–actinolite skarns, and plagioclase skarns both the α- and the β-forms occur, the β-form being the commoner of the two. Zoisite has been found in the pale-amphibole skarns and the prehnite and pectolite skarns; where determined in the two latter skarn types it has always proved to be β-zoisite. The optical distinctions
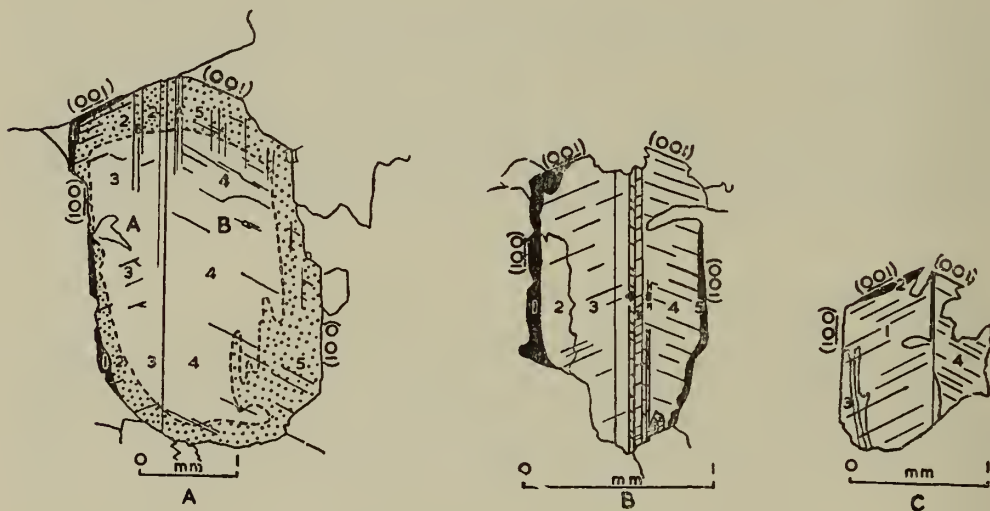

FIG. 7. Minerals of the epidote group: epidote shown black, extinction angles in Table V. A, Clinozoisite–epidote crystal in epidosite, Torr Buidhe (cf. Pl. 2, fig. 1). B, C, Clinozoisite–epidote crystals in epidosite, Balnagrantach.

between α- and β-zoisite here employed are those of Termier, given in Winchell (1951). These distinctions are consistent and no anomalies are apparent amongst the zoisites studied.

The crystals show zones of anomalous Berlin blue and of grey and buff interference colours. The boundaries between these colours often parallel a prismatic (100) parting; elsewhere they are irregular.

In two outcrops a bright pink zoisite (thulite) has been found, both in the limestone quarry above Kilmichael Church. In one case the thulite occurs disseminated in a rock which, although perhaps transitional to a skarn, has been grouped with alkali-injected limestones (Part I, p. 127). In the second case the thulite occurs as a centimetre-wide vein in actinolite skarn. The mineral is optically positive

with a very small optic axial angle ($r > v$, distinct), the optic axial plane is parallel to (001), and straight extinction may be observed in (010) sections ; these data prove this thulite to be related to β-zoisite.

Clinozoisite and epidote. These minerals are together about as common in skarns of Group I as is zoisite. They are usually in crystals with complex zoning, having clinozoisite cores and narrow, impersistent epidote rims. This apparently indicates a slight iron enrichment in the metasomatic fluids towards the close of the period of skarn formation. The epidote is colourless and non-pleochroic. It is, to judge from its optical properties, iron-poor, having little more than 10% of the $Ca_2Fe_3Si_3O_{12}OH$ molecule.

Compositions have been determined by the angles of extinction to the (100) cleavage. These are best seen where the crystal is twinned on (100) and the section is normal to the (001) cleavage, that is to the b crystallographic axis (Text-fig. 7 and Pl. 9, fig. 1).

As with the same mineral group in the limestones, no β-clinozoisite has been found (this has a negative extinction angle exceeding 45°, Johnston, 1949). Extinction angles determined in these minerals in the skarns range from $-6°$ (clinozoisite to $+3°$ (epidote), as shown in Table V.

TABLE V.—*Extinction Angles in Twinned Clinozoisite–Epidote Crystals*

($\alpha \wedge c$ measured $\perp b$. The angle is positive in epidote, negative in clinozoisite ;
the crystals A, B and C appear in Text-fig. 7)

A			B			C	
LH	RH		LH	RH		LH	RH
$1 = +3°$	$4 = -6°$	.	$1 = +3°$	$4 = -2°$	.	$1 = -2°$	$4 = -1°$
$2 = -2°$	$5 = -2°$	.	$2 = -0.5°$	$5 = +3°$	.	$2 = +3°$	—
$3 = -6°$	—	.	$3 = -4°$	—	.	$3 = -1°$	—

Epidotes, but no clinozoisites, are recorded from the pale-amphibole skarns. The pectolite and prehnite skarns sometimes contain large zoned clinozoisite–epidote crystals up to 3 mm. across. They display polarization tints in blues and lemon yellows, with zoning brought out by these colours.

Amphiboles. These are perhaps the most important minerals of the Glen Urquhart skarns. The amphibole of the skarns of Group I is a dark green prismatic type, which might be termed actinolite in the field. Chemical analysis (Table VI, 1) shows that it is both too aluminous and too magnesian to fall into the actinolite group as currently defined (Winchell, 1951); the mineral can best be styled a magnesia-rich hornblende. Trace elements in this amphibole are set down in Table VII, 1 and its optical properties in Table VIII, 1. Its chemistry and optical properties are probably typical of amphiboles in Group I skarns, although extinction angles of 20° and more are recorded amongst them.

TABLE VI.—*Analyses of Skarn Clinoamphiboles*

	1	1a	2	2a	3	3a	4	4a
SiO₂	52·51	7·390 } 8·00	52·87	7·367 } 8·00	52·4	7·243 } 8·00	51·67	7·178 } 8·00
Al₂O₃	5·12	0·610 / 0·240	6·40	0·633 / 0·418	7·1	0·757 / 0·400	5·75	0·822 / 0·199
TiO₂	0·22	0·024	0·28	0·029	0·2	0·021	—	—
Fe₂O₃	2·45	0·260	1·12	0·117	—	—	2·86	0·299
FeO	5·28	0·621 } 4·98	2·37	0·276 } 5·77	3·4	0·393 } 4·88	23·37	4·836 } 5·25
MgO	18·21	3·818	20·52	4·929	19·7	4·055	—	
MnO	0·15	0·018	0·06	0·001	0·1	0·012		
CaO	12·86	1·938 } 2·18	13·50	2·018 } 2·10	13·4	1·983 } 2·29	12·42	1·848 } 2·20
Na₂O	0·73	0·200	0·56	0·076	0·9	0·241	0·75	0·202
K₂O	0·25	0·045	0·12	0·010	0·4	0·070	0·84	0·148
H₂O+110° C.	1·88	1·764 } 1·98	1·60	1·486 } 1·62	2·2	2·027 } 2·28	[2·16]	2·000 } 2·00
H₂O−110° C.	0·09	—	0·09	—	—			
F	0·40	0·179	0·30	0·132	0·58	0·253		
	100·15		99·79		100·3⁸		[99·82]	
Less O≡F	0·17		0·13		·24			
	99·98		99·66		100·1⁴			
D (gm./cm.³ ± 0·02)	$D_4^{21\cdot5}=3\cdot05$		$D_4^{20}=3\cdot01$		$D_4^{22}=3\cdot02$		$D=3\cdot059$	
A	139		137		124		117	
B	18		10		29		20	
C	177		185		184		189	

$A = 100\ Si - 600$

$B = 100\ (Ca + Na + K) - 200$

$C = \dfrac{200\ (Mg + Al^{vi})}{Mg + Al^{vi} + Fe'' + Fe''' + Mn + Ti}$

Co-ordinates for an amphibole plot given by Winchell (1945). (Al = Al in the Y group).

1. *Magnesia-rich hornblende*, from hornblende–epidote–plagioclase–quartz–calcite skarn, hillside just north of Lochan an Torra Bhuidhe, Glen Urquhart.
2. *Magnesia-rich hornblende* in pale amphibole–plagioclase skarn, containing a trace of SrO, 140 m. north-west of Loch an Sgòr Gaoithe, Glen Urquhart.
3. *Magnesia-rich hornblende* ("*edenite*"), in pale amphibole skarn, small quarry, 50 m. south-east of largest quarry, Upper Gartally, Glen Urquhart.
4. "*Edenite*", Edenville, Orange Co., N.Y., description and analysis by C. Rammelsberg (1858).[1]
Column "a," for each analysis represents cations per 24(O, OH, F).
Analysts: for 1 and 2, D. I. Bothwell and K. C. Chaperlin; for 3, K. C. Chaperlin (using for 3 the rapid method of silicate analysis).
Fluorine determinations: 1 and 2, S. R. Nockolds; 3, C. F. M. Fryd.

[1] The summation of this analysis given by Rammelsberg is about 2% low, and the figure for water (0·46%) is lower than the average for hornblendes by a similar amount; all other values are reasonable. The deficit in the summation has therefore been taken as due to a faulty determination of water (i.e. loss on ignition) and the value for H₂O has been arbitrarily obtained by assuming the value OH = 2·00 in the formula. The error introduced into the H₂O+ figure will probably not exceed 1% of that figure.

TABLE VII.—*Trace Elements in Skarn Clinoamphiboles*

(parts per million)

	1		2		3			1		2		3
Ga	.	9	.	7	.	*	Zr	.	37	.	37	.	45
Cr	.	47	.	100	.	70	Y	.	*	.	12	.	10
V	.	95	.	95	.	45	La	.	N.D.	.	N.D.	.	*
Mo	.	*	.	*	.	*	Sr	.	10	.	10	.	50
Sn	.	*	.	*	.	*	Pb	.	*	.	*	.	*
Li	.	2	.	2	.	3	Ba	.	30	.	30	.	30
Ni	.	21	.	21	.	22	Rb	.	*	.	*	.	*
Co	.	6	.	6	.	5	Cs	.	N.D.	.	N.D.	.	*
Sc	.	*	.	*	.	*							
F	.	4000	.	3000	.	5800†							

1, 2, 3, as for Table VI. Trace element determinations by Dr. S. R. Nockolds.
* = present, but below the limit for quantitative determination of this element (see Nockolds and Allen, 1953).
† Determination by C. F. M. Fryd.

TABLE VIII.—*Optical Constants of Skarn Clinoamphiboles*

No. as in Table VI		Refractive indices : Na light ($\pm$ 0·002)		Optic axial angle : Na light		Extinction $\gamma \wedge c$ (in plane $\perp b$)		Pleochroic scheme
1	.	$\alpha = 1 \cdot 623$ $\beta = 1 \cdot 634$ $\gamma = 1 \cdot 642$	.	$- 83°$	.	$18°$	.	α colourless. β greenish straw. γ pale leaf green.
2	.	$\alpha = 1 \cdot 615$ $\beta = 1 \cdot 627$ $\gamma = 1 \cdot 638$	.	$- 88°$	.	$18°$	.	colourless.
3	.	$\alpha = 1 \cdot 613$ $\beta = 1 \cdot 623$ $\gamma = 1 \cdot 637$	.	$- 84°$	.	$20°$	.	colourless.

The characteristic amphibole of Group II, the pale-amphibole skarns, was separated from a rock composed almost wholly of the mineral, together with a small amount of zoned plagioclase (An_{33}, average), and trace quantities of zircon and iron ore. Its chemical composition is set down in Table VI, 2, its trace elements in Table VII, 2 and its optical constants in Table VIII, 2. It may be regarded as a magnesia-rich hornblende, being more magnesian than, but otherwise of similar composition to the amphibole of the skarns of Group I.

Also to be found amongst the pale-amphibole skarns are the amphiboles called "edenite" by Heddle (1901, Vol. II). As noted in Part I of this *Bulletin* some pale-green fibrous and fasciculitic amphibole corresponding to Heddle's "edenite" occurs in the limestone but there is more of this material, and also a pale slate-blue amphibole of similar habit, in the skarns (which were not recognized as a separate rock group by Heddle). A powdered sample of the latter type, from an almost monomineralic rock, was cleaned of traces of calcite and plagioclase and analysed.

Its chemical composition is given in Table VI, 3, its trace elements in Table VII, 3 and its optical constants in Table VIII, 3. The chemical analysis of the " edenite " was carried out by the rapid spectrophotometric method and results are quoted to 0·1%, by weight, only. The analysis is, however, likely to be of the same order of accuracy as the other two, and the three may reasonably be discussed together.

The three amphiboles agree in possessing calcium approximating to 2 atoms per formula unit, moderately high alumina, a high Mg/Fe″ ratio, and alkali atoms that must be assigned to the vacant space in the amphibole lattice. In addition their trace element contents are closely comparable. The comparison is most marked between nos. 1 and 2, which, along with similarities in major elements, supports the supposedly similar time and mode of formation of the two skarn types containing these two amphiboles. No. 2 is slightly further removed from 3 in trace element content although both belong to pale-amphibole skarns.

The theory that the skarns arose by metasomatic diffusion and commingling of materials at the boundaries between limestone and kyanite schist is supported in the analyses of these three amphiboles. Their calciferous and aluminous composition reflects the contributions of the two parent rocks, whilst their high Mg/Fe″ ratios suggest that the magnesia brought to them from the limestone (which is appreciably magnesian in bulk composition) must have dominated iron brought in from the kyanites chists, or any other source. In one case anthophyllite has been observed forming at an early stage of the transformation of kyanite schist to pale-amphibole skarn. This probably indicates the transport of magnesia in advance of lime from the limestone to a kyanite schist host rock.

The alumina content and the moderate filling of the vacant spaces by alkali atoms remove these three skarn amphiboles from either of the two fields of limestone amphiboles shown by Hallimond in his graphical plot for calciferous amphiboles (1943, fig. 3). They fall in a field to which he has given the general heading of " schists ". The optical constants of these amphiboles conform to the curves set down by Winchell (1945, fig. 7 etc.) ; in particular they all plot within the field of optically negative amphiboles.

The name " edenite " was originally given by Breithaupt (1847) to an amphibole from " Eden " (Edenville, Orange County, New York). The first analysis of an amphibole designated " edenite " from Edenville is given by Rammelsberg (1858).[1] This analysis is plotted in Text-fig. 8, together with the three amphiboles of the present study, Heddle's tremolite (see p. 128), and his two " edenites ". Also plotted are an amphibole from Edenville named " edenite " by Winchell (1931), and an " edenite " from South India (Subramaniam, 1956).

Rammelsberg's analysis is of early date and probably incomplete, but it can be recalculated to a respectable distribution of atoms (Table VI). It may thus be taken as having priority, and as providing a fair guide to the composition of the type material. Heddle was correct in naming his slate-blue amphibole " edenite " on the data available to him. The three amphiboles described in the present study are also similar to Rammelsberg's mineral (Table VI and Text-fig. 8). Heddle's pale-

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[1] Rammelsberg records the mineral as the " edenite " of Breithaupt, but he prefers to call it hornblende.

green " edenite " is not close to the original nor are those of Winchell or of Subramaniam (Text-fig. 8). Winchell's analysis lies well beyond the probable limits of analytical error in Rammelsberg's analysis and cannot be accepted as a repeat analysis of the type material. Still less can the composition $NaCa_2Mg_5AlSi_7O_{22}(OH)_2$ be labelled " edenite ".
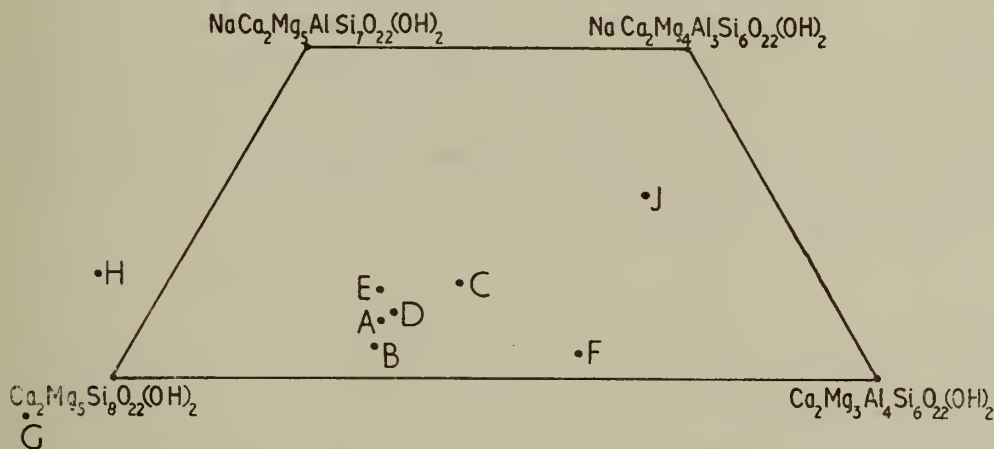

FIG. 8. Hallimond plot of the field of calciferous amphiboles. The amphiboles mentioned in the text are lettered as follows :

A, magnesia-rich hornblende, Glen Urquhart (Table VI, 1) ;
B, magnesia-rich hornblende, Glen Urquhart (Table VI, 2) ;
C, magnesia-rich hornblende, Glen Urquhart (Table VI, 3) ;
D, " edenite ", Edenville, New York (Rammelsberg, 1858, and Table VI, 4 of this study) ;
E, " edenite ", Glen Urquhart (Heddle, 1901, vol. II) ;
F, " edenite ", Glen Urquhart (Heddle, 1901, vol. II) ;
G, tremolite, Glen Urquhart (Heddle, 1901, vol, ii, and see p. 128–129 of this study) ;
H, " edenite ", Edenville, New York (Winchell, 1931) ;
J, " edenite ", Sittampundi, Madras (Subramaniam, 1956).

This last usage was introduced by Berman (1937) who employed the term " edenite-hornblende ". The same theoretical formula or " end member " has been called " edenite " by (e.g.) Winchell (1945, 1951), Sundius (1946), and Subramaniam (1956). The composition $NaCa_2Mg_5AlSi_7O_{22}(OH)_2$ lies in the optically positive field in Winchell's diagram (1945) whilst Rammelsberg's mineral lies in the optically negative field (as confirmed, e.g., by optical constants of the Glen Urquhart amphiboles ; Table VIII). The above theoretical composition is merely an unlabelled point in a variation diagram, in an area unrepresented by any amphibole analysis,[1] and does not merit baptism under the name already given to an amphibole chemically and no doubt optically distinct therefrom.

As for the Breithaupt–Rammelsberg mineral it lies within the field of the common

[1] Sundius (1946 : 20) himself pointed out that no analyses exist of amphiboles close to $NaCa_2Mg_5AlSi_7O_{22}(OH)_2$.

hornblendes and it therefore seems advisable to discard the term "edenite" altogether.

Pyroxenes. The clinopyroxene salite is common amongst the skarns of Group I, but when it is associated with amphiboles the latter predominate. It is leek-green, and often of coarse prismatic growth. In places it may form a pyroxene rock. One such rock (from which the analysed sample was separated) contains prisms up to 3 cm. × 1·5 cm. in size. There is in this rock late growth of calcite, zoisite, and prehnite together with occasional large sphene crystals. As with the pyroxenes of the limestones, hornblende needles commonly "spear" through the skarn pyroxenes, whilst in certain of the plagioclase skarns hornblende needles fringe the pyroxene crystals. The analysis, trace element content, and optical constants of the salite appear in Table IX, 1. Its optics agree well with the curves for clino-pyroxenes published by Hess (1949).

TABLE IX.—*Skarn Clinopyroxenes*

	weight per cent			cations per 6 [O],			parts per million (weight)	
	I	2		I	2		I	2
SiO_2	52·96	53·65		1·937 ⎱2·00	1·961 ⎱2·00		Ga	2	5
Al_2O_3	1·21	1·89		⎧0·033⎰ ⎨0·020⎩	⎧0·039⎰ ⎨0·042⎩		Cr	500	45
TiO_2	0·10	0·04		0·002	0·001		V	100	67
Fe_2O_3	0·49	0·58		0·013	0·016		Mo	*	*
FeO	6·00	1·53		0·185 ⎱1·10	0·047 ⎱0·99				
MnO	0·56	0·09		0·018	0·003		Li	10	8
MgO	14·02	16·23		0·780⎰	0·883⎰		Ni	500	10
CaO	24·29	25·30		0·967 ⎱0·99	0·990 ⎱1·00		Co	50	3
Na_2O	0·36	0·19		0·027⎰	0·013⎰		Sc	40	*
K_2O	0·02	Tr.		—			Zr	50	37
H_2O+ 110° C.	0·23	0·47					In	*	N.D.
H_2O- 110° C.	0·20	0·07					Y	10	*
F	N.D.	N.D.					La	*	N.D.
	100·44	100·04					Sr	5	112
D(gm./cm.³)	D_4^{21}=3·34	D_4^{18}=3·28					Pb	*	*
± 0·02							Ba	*	10
							Rb	*	*
							Cs	*	N.D.

1. *Salite*, in salite–hornblende–zoisite–calcite–prehnite skarn, south flank of Sgòr Gaoithe, Glen Urquhart. *Anal.* G. H. F. Refractive indices in sodium light ($\pm$ ·002), $\alpha = 1·677$, $\beta = 1·686$, $\gamma = 1·706$; $2V\gamma = 58°$; $\gamma \wedge c = 41°$; colour grey, non-pleochroic; atomic percentages, $Ca_{49·3}$ $Mg_{39·7}$ $Fe_{11·0}$.

2. *Diopside*, in diopside–zoisite–amphibole–calcite skarn, north side of knoll 250 m. north-west of Lochan an Sgòr Gaoithe, Glen Urquhart. *Anals.* D. I. Bothwell and K. C. Chaperlin. Refractive indices in sodium light ($\pm$ 002) $\alpha = 1·665$, $\beta = 1·672$, $\gamma = 1·695$; $2V\gamma = 57°$; $\gamma \wedge c = 39°$; colourless; atomic percentages, $Ca_{51·1}$ $Mg_{45·1}$ $Fe_{3·8}$.

Trace element determinations by Dr. S. R. Nockolds; *, present, but below the limits for quantitative determination of this element (see Nockolds & Allen, 1953).

A waxy-white diopside occurs sporadically in the pale-amphibole skarns. It is in chunky prisms up to 5 mm. in length, forming an almost monomineralic rock. The accessory minerals are zoisite, pale amphibole, calcite, sphene, and zircon. Where it grades into the normal skarn it can be seen under the microscope that the amphibole spears into and replaces the pyroxene. The analysis, trace element content and optics of this diopside are set down in Table IX, 2. It appears to be among the purest natural diopsides analysed. Those of De Kalb, New York (Zimányi, 1893), Cascade Canyon and Crestmore, California (Merriam & Laudermilk, 1936), and Organ Mountains, New Mexico (Dunham & Peacock, 1936) are purer, Cascade Canyon being the closest to $CaMg(SiO_3)_2$. The Organ Mountains diopside, like the Glen Urquhart mineral, contains some alumina. A large amount of alumina is not, in fact, to be expected in the latter diopside for Tilley (1938) has shown that diopsides rich in alumina (" fassaites ") occur in spinel-bearing metamorphosed limestones, and spinel is absent from the Glen Urquhart skarns. Segnit (1953) has shown, by a study of synthetic specimens, that an increase in alumina diminishes the birefringence and increases the optic axial angle of diopsides. The Glen Urquhart diopside is apparently insufficiently aluminous for its birefringence to be measurably affected and its optic axial angle is in fact only diminished 2° with respect to pure synthetic $CaMg(SiO_3)_2$; the refractive indices are each 0·001 higher than the pure synthetic material, the extinction angles of the Glen Urquhart, and the synthetic diopsides are practically identical (cf. Wright & Larsen, 1909). The analysis of the diopside from the pale-amphibole skarns re-emphasizes the high Mg/Fe'' ratio of the dominant minerals (and therefore the rock) of this skarn group.

Plagioclase. This feldspar is a stable phase in the Group I and Group II skarns (attaining importance in the plagioclase skarns). In these Groups the mineral develops from the groundmass as porphyroblasts, and in symplectites. Zoning and patchy replacement are usual in these feldspars. They range in composition from An_6 to An_{47}. The plagioclase of the Group III skarns is a relict mineral surviving from the kyanite schist host (composition : An_{32-38}, zoned). In highly metasomatized rocks of this Group it is replaced by a fine-grained aggregate of prehnite. Stages in this replacement may be studied in thin section.

Chlorite. All three skarn Groups contain chlorite. For the most part it is optically positive and shows grey polarization tints, low in the first order of birefringence. Amongst the Group III skarns the chlorites may reach a diameter of 1·5 mm. In some cases they can be seen in thin section to be interleaved with hydrobiotite, recalling the submicroscopic mixture of the two minerals described by Barshad (1948) in a mixed-layer mineral from Lenni, Pennsylvania.

An unusual rock associated with the epidosites of Group I on Torr Buidhe is made up of areas of fine-grained, dark-green chlorite interspersed with pale pink blotches composed of irregularly intergrown calcite, quartz, albite, and muscovite, with abundant apatite. The chlorite is in mossy, almost spherulitic growth. The green colour masks the true interference colour but the birefringence appears to lie between 0·004 and 0·010. Cleavage flakes have a refractive index β of 1·593 (in sodium light : $\pm$ 0·002) and show $2V\gamma$ near 0°. These figures suggest that the mineral may be sheridanite, variety grochauite (Hey, 1954).

Hydrobiotite. In the Group III skarns a transition can be followed, under the microscope, from normal biotite of kyanite schist to a biotite-like mineral in pecto-lite and prehnite skarns, having sinuous foliae with stringy, or rat-tail edges and much prehnite growing between the cleavages. The sinuous mica is closely comparable in thin section to the investigated hydrobiotite in nearby hydrothermal bodies of the same age (Francis, 1955). It shows limited exfoliation on sudden heating, and is presumably also hydrobiotite.

Prehnite. This mineral, which is abundant in the skarns of Group III, has been identified chiefly by means of X-ray powder photographs. In much-altered rocks it occurs as a polycrystalline aggregate in the groundmass, and in white veins. For the most part it is biaxial positive, with a moderate optic axial angle and bire-fringence up to 0·020 in bright second-order colours. A mineral of very similar microscopic appearance, containing, like the prehnite, abundant dusty inclusions, was found to be sensibly uniaxial (negative). A crystal (from a white vein in the skarn) detached from a thin section gave : $\alpha = 1·612$, $\beta = \gamma = 1·652$ (sodium light), $2V\alpha \sim 0°$. This fragment yielded the X-ray powder pattern of prehnite ; the vein from which it came is white and apparently monomineralic, and several of its crystals are seen to be uniaxial negative under the microscope. This vein can be distinguished in the hand specimen, and a sample from it also gave the X-ray powder pattern of prehnite.

Winchell (1951 : 360) records the frequent occurrence of a variety of optical anomalies in prehnite (including oscillation of the optic plane, apparent reduction of the optic axial angle, etc.). It is an open point as to whether these anomalies are sufficient to explain the optically negative character and high birefringence of the present material. Prehnite occurs in the interstices between salite crystals in the pyroxene-rich skarn which yielded the analysed salite on Sgòr Gaoithe (Pl. 9, fig. 2).

Pectolite. Identification of this mineral has also been by X-ray powder photo-graphy. It is a white crystalline aggregate in the groundmass and in veins in the Group III skarns. Although very similar in appearance and in birefringence (middle second-order) to prehnite it has a more markedly fibrous habit. The typical habit is in sprays, rosettes and sheaves not usually exceeding 1·0 mm. in length. The fibres have positive elongation. Pectolite is never associated with relict kyanite which is always associated with prehnite in these skarns. A pectolite vein has been identified in a salite-rich skarn of Group I, close to the locality of the analysed salite.

Xonotlite. Fine, brownish, opaque fibres, filming pre-existing minerals, are common in the skarns. In one locality they form veins, white in hand specimen, reaching 6 cm. in width, cutting across diopside–hornblende skarn of Group I. The veins incorporate small blocks of skarn without apparent reaction. They are exposed in the Gartally burn where the skarns are adjacent to the margin of the serpentinite mass, above the village of Milton. The veins are made up of sheaves of radiating fibres, milky-white and clear at their centres, brownish and opaque at their extremities. This relates to their state of hydration. The centres of the sheaves are xonotlite, the margins may be close to tobermorite (Dr. J. D. C.

McConnell, personal communication).   The fresh fibres have positive elongation and a birefringence of about 0·014, with a refractive index for light vibrating parallel to their length of 1·587 (sodium light ; ± 0·002) ; they are optically positive. The type material from Tetela de Xonotla, Puebla, Mexico, and the Isle Royale, Michigan xonotlite have higher refractive indices (1·593, 1·594 respectively). Spacings of the lines in X-ray powder photographs of the type mineral and the Glen Urquhart mineral are given in Table IX. The Isle Royale xonotlite has similar spacings except that the one at 8·59 Å. is not recorded.

Heddle (1901, vol. II) has recorded wollastonite from outcrops nearby, recently described as zoned hydrothermal bodies in serpentinite (Francis, 1955), close to the Free Church of Milton.   His two analyses report too much water to be considered as pure wollastonites, and they are accompanied by specific gravities (each 2·175), closer to xonotlite (2·17) than to wollastonite (2·915).   It appears that Heddle's materials were both xonotlite.

TABLE X.—*Xonotlite : X-ray Powder Photograph Spacings and Intensities*

Line No.	A d(Å.)	A I	B d(Å.)	B I/I_1	Line No.	A d(Å.)	A I	B d(Å.)	B I/I_1
1	8·59	vw	8·59	30	17	1·86	vw	—	—
2	7·03	s	7·06	70	18	1·84	vw	—	—
3	4·27	s	4·24	90	19	1·83	vw	1·83	70
4	—	—	3·89	90	20	1·75	—	1·74	30
5	3·64	s	3·62	30	21	1·71	—	1·70	70
6	3·51	w	3·44	10	22	1·68	—	1·68	10
7	3·25	s	3·23	90	23	1·65	—	—	—
8	3·09	m	3·06	100	24	1·64	—	1·63	40
9	2·89	m	2·82	90	25	1·60	—	1·59	40
10	2·70	s	2·69	70	26	1·56	vw	1·57	40
11	2·64	w	2·62	10	27	1·52	—	1·51	70
12	2·51	m	2·50	70	28	—	—	1·42	60
13	2·33	m	2·33	30	29	1·39	—	1·38	60
14	2·25	m	2·25	40	30	—	—	1·36	10
15	—	—	2·03	90	31	1·33	—	1·35	10
16	1·95	m	1·94	90	32	1·32	—	1·32	30
					33	1·31	—	1·30	30

A. Xonotlite, Gartally Burn, Milton, Glen Urquhart.
B. Xonotlite, Tetela de Xonotla, Puebla, Mexico. (A.S.T.M. Index 2–0598 (ICI–N).)

Other minerals (including accessories). Calcite and quartz are recorded in all three skarn Groups, as are accessory sphene, zircon, and magnetite.   Biotite, some of it phlogopitic, is common in Group I.   It is partly relict from the schist host, but is often in apparently stable growth.   In Group II small amounts of phlogopite are stable, whilst the biotite in Group III, mentioned above, is in early stages a relict from the schists, later to be transformed into hydrobiotite.   Muscovite is stable in Group I, but is a relict mineral, appearing only in the early stages, in Group III.

Garnet, staurolite, and kyanite are also disequilibrium minerals in Group III, although they persist, in part, into the most altered rocks.   The refractive index

of the garnet is 1·786 (sodium light : ± 0·003), a slightly lower value than the average for kyanite schist garnets in Glen Urquhart (1·796). Garnets in Group III are deep-red, xenoblastic and reach 6 cm. in diameter.

Of the remaining accessory minerals pyrite and apatite occur in Groups I and II, rutile in Groups I and III (abundantly and in large crystals in the latter), graphite in Group II, and serpentine in Group III.

Petrology

Group I : Epidosites, epidote–hornblende skarns and plagioclase skarns. The parageneses observed in this Group are set down in Table XI. The great variability of the Group is evident. There are seldom more than two representatives of a paragenesis amongst the slides examined. The appearance and nature of the epidosites and epidote–hornblende skarns has been sufficiently covered in preceding pages and it remains to describe in greater detail the plagioclase skarns and transitions between them and the first two types. These rocks, of insignificant areal extent, are found close to the serpentinite margin. The host rock is always kyanite schist, and early stages of transformation are always marked by the crystalloblastic growth of large plagioclases (Text-fig. 9). At a later stage the whole rock may be composed of plagioclase (oligoclase). It is always poorly crystallized, showing patchy extinction, ragged intergrowth, irregular boundaries and other signs of replacement.

FIG. 9. Polished face of a hand specimen of mica schist showing oligoclase porphyro-blasts that have grown into a distinct mineral zone and have thrust themselves out into the groundmass of the host-rock.

On the south flank of the hill Sgòr Gaoithe, close to the salite rock and to the serpentinite margin, is a mass of plagioclase rock outcropping over an area of several square metres. Its junction with kyanite schist is well exposed. It is a sharp boundary with mineral zoning. The schist near the boundary, although mapped with the kyanite schist, has not been observed to contain any kyanite or the normal accessory rutile of this schist. It is otherwise mineralogically and texturally similar to the kyanite schists. The first new mineral to appear towards the boundary is sphene in crystals up to 1 mm. diameter. Immediately thereafter appear porphyroblasts of oligoclase up to 2 mm. across. They have ragged edges towards the quartzo-feldspathic ground, and wavy extinction. At this stage, also, coarse clinozoisite comes in. The biotite of this zone is split and interleaved with prehnite. The next stage involves the resorbtion of biotite, plagioclase, and quartz and the formation of a pale-green, prismatic amphibole ($\gamma \wedge c = 18°$; pleochroism : α, colourless ; β, pale grass-green ; γ, grass-green). The amphibole grows in quantity (at the expense of the remaining minerals of the schist) until it forms, with occasional sphene crystals, a distinct mineral zone. (Pl. 9, fig. 3). At this stage the amphibole has slightly different optics ($\gamma \wedge c = 22°$; pleochroism α, β, colourless ; γ pale grass-green) suggesting an increased Mg/Fe″ ratio. The inner margin of this zone probably represents the primary junction of the schist with the plagioclase rock. The amphibole zone is separated from the plagioclase rock by a narrow rim of " mossy " clinozoisite. Some " islands " of plagioclase, which lie within the amphibole zone, are also fringed with mossy clinozoisite. The plagioclase within the body of plagioclase rock has the composition An_{40}, that close to the mineral zones is more sodic (An_{28}). A number of thin calcite veins can be seen in the plagioclase rock. The feldspar is considerably altered by an overgrowth of calcium-silicate-hydrate material, especially near to the mineral zones.

As suggested, the first-formed boundary apparently lay between plagioclase rock and schist. Alterations in the schist, with added material (possibly coming from the direction of the plagioclase rock) may then have led to the formation of the amphibole zone, adjacent to the boundary surface. Lastly the clinozoisite would develop between the plagioclase rock and the amphibole zone. This order of growth is convenient for picturing the changes but cannot be demonstrated. The zones may have arisen in a different order or simultaneously. Chemical reactions for the changes cannot profitably be set down in the absence of analyses of the participating phases (feldspar, biotite, amphibole, and clinozoisite). The influence of lime is, however, clear (and receives support from the veining and overgrowths of lime minerals in the plagioclase rock). Kyanite and rutile, usually present in the schists, seem, with the addition of lime, to have contributed anorthite (in the plagioclase) and sphene to the marginal part of the schist. Biotite, with absorption of lime and loss of potash, has altered to amphibole. Plagioclase rock near the margin with the schists has been de-calcified and the liberated anorthite has probably united with excess lime to produce clinozoisite. The clinozoisite, needing a small amount of ferric iron, is localized at the margin of the amphibole zone, from which it presumably withdrew (and oxidized) the necessary iron.

Table XI.—*Skarn parageneses*

Group I Skarns

zo-qtz-plag-hb

zo-qtz-plag-mu-hb

zo-plag-hb-di-ct

zo-plag-hb-di-ct-xon

zo-chl-hb-di

zo-hb-di

zo-hb-xon

zo-hb-di-xon

zo-di

zo-hb-di-preh

clz/ep-qtz

clz-qtz-plag-hb

clz/ep-qtz-plag(An_{28})-bi-hb

clz/ep-qtz-plag(An_{29})-mu-bi-hb-di

clz/ep-qtz-plag(An_{40})-bi-hb-di-ct

clz/ep-qtz-di

clz/ep-qtz-hb-di

clz/ep-qtz-hb-ct

clz/ep-qtz-hb-ct-pect

clz/ep-plag(An_{15})-bi-hb

clz/ep-plag-chl-ct-xon

clz/ep-plag(An_{29})-phlog

clz/ep-hb

clz/ep-hb-di

clz/ep-bi-hb-di-ct

ep-qtz-plag-hb-di

ep-qtz-plag-hb-ct

ep-qtz-plag-bi-hb-xon

ep-qtz-hb

ep-bi-hb-di-ct

qtz-plag(An_6)-mu-chl-ct

Group II Skarns

trem-zo-di-ct

trem-ep-qtz-plag (An_{36-47})-di

trem-ep-qtz-plag-chl

trem-qtz-ct

trem-qtz-ct-phlog

trem-qtz-plag (An_{23})-phlog

trem-plag (An_{33})

anth-qtz-plag (An_{28})-mu-bi

Group III Skarns

preh-bi-mu-zo-plag(An_{40})-qtz-chl

preh-pect-hbi-chl-ct

preh(?)-pect-hbi-mu(?)-plag(An_{36})-qtz-chl

pect-clz/ep-plag(An_{32})-chl-ct-xon

preh-pect-hbi-mu-zo-dsp-gar-ky-st-chl-ct-xon

Accessories: allanite, apatite, graphite, magnetite, pyrite, rutile, serpentine, sphene, zircon.
Abbreviations in Table XI: as in Table II, p. 130, and also: anth, anthophyllite; dsp, diaspore, hbi, hydrobiotite,; ky, kyanite; pect, pectolite; preh, prehnite; st, staurolite; xon, xonotlite.

Similar relationships to the above have been found in several rocks near to the serpentinite contact. Sometimes the fringes of clinozoisite are larger than those on Sgòr Gaoithe, and are seen to be delicate plagioclase–clinozoisite symplectites. The host is plagioclase whilst the dactylites are clinozoisite. Diopside may be present in these rocks. It is usually fringed with fine-grained amphibole needles, in parallel growth. This late-stage amphibole is not fringed with clinozoisite at its boundaries with plagioclase. Thin prisms of late-stage amphibole " spear " through other minerals in all the Group I skarns, as they do in the limestones.

Group II: Pale-amphibole skarns. Only a restricted number of rock types has been found in this skarn Group, (Table XI). The pale-coloured magnesian hornblende which dominates these skarns, and the subordinate diopside and phlogopite which accompany it (see above) impose a high Mg/Fe″ ratio on the rock. As suggested, magnesia has probably been contributed in much greater amount from the limestone (originally of magnesian type) than has ferrous oxide from the kyanite schist or any other source.

Some specimens reveal transitions from kyanite schist to skarn. In one case needles of anthophyllite are collected in clusters of late, " spearing " growth. They are particularly associated with biotite of the schist, and seem to replace it. Some extra magnesia would probably be needed for this transformation, whilst potash

is carried away. The anthophyllite is soon converted to the normal clinoamphibole of the skarn, with the arrival of lime. The latter seems, in this case, to lag behind transported magnesia. The potash liberated in the alteration of the biotite probably contributes to pseudomorphs of " shimmer-aggregate " white mica after kyanite which characterize an early stage in the replacements. This white mica apparently does not survive into the final skarn parageneses. It may unite with introduced magnesia to form phlogopite. Plagioclase becomes very turbid during the metasomatism and both it and quartz are diminished, or even eliminated during the changes.

Group III : Prehnite and pectolite skarns. Mineral assemblages of these skarns are set down in Table XI. Amongst the rocks studied the most thoroughly metasomatized specimen was collected by Dr. H. I. Drever, and kindly loaned to the author for study (paragenesis 5). At the locality close to the limestone isoclines (the northern locality) rocks illustrating the earliest stages of alteration are not difficult to find. Dr. Drever's specimen is also from this area, but it is apparently a rarity as no similar rocks have been found. At Sgòr Gaoithe (the southern locality) these skarns are only known in a state of alteration approaching that of Dr. Drever's specimen.

At the northern locality unaltered kyanite schist with fresh kyanite porphyroblasts can be seen passing into a biotiteschist, impoverished in muscovite and containing pseudomorphs of " shimmer-aggregate " white mica after kyanite which stand proud on weathered surfaces. Identical pseudomorphs occur in alkali-injected kyanite schists in Glen Urquhart, as will be described in a further study. The latter seem clearly to be due to the addition of potassium to the system, but the skarns of Group III lie outside the area affected by potash metasomatism. An interesting early stage in the alterations can be studied in a slide in which the muscovitization of kyanite has been only half completed before this type of alteration has yielded to lime-metasomatism. A relict core of kyanite in " shimmer-aggregate " has been converted to twinned and zoned prismatic clinozoisite, whilst the " shimmer-aggregate " appears to have taken up some prehnite (Pl. 9, fig. 4). Plagioclase in this rock is, in general, fresh and strongly twinned on the albite and pericline laws. It has the composition An_{40}. In patches and in threads along cleavages are fine-grained, brightly-polarizing minerals introduced into the feldspar. These appear to be prehnite and muscovite.

At the later stages of alteration represented at both localities quartz and plagioclase are eliminated, biotite has become hydrobiotite, and prehnite and pectolite have greatly increased in quantity. Diaspore occurs in some slides. Epidote minerals are common. Late veins of calcite and overgrowths of xonotlite can be found in most of the specimens. Kyanite crystals, with inclusions of staurolite, persists as unstable relicts in Dr. Drever's rock. The significance of staurolite inclusions in kyanite in Glen Urquhart has been discussed elsewhere (Francis, 1956*b* : 356). The relict crystals lie in pools of prehnite aggregate. Garnets in the same rock reach a size unknown in the kyanite schists that are not affected by metasomatism ; there appears to have been some solution and redeposition of these crystals, accompanied by a small compositional change, at an early stage in the metasomatism.

TABLE XII.—*Chemistry of Skarn Formation*

	1	2			1a	Difference	2a
SiO_2 .	61·86	43·20	Si .		57·89	−20·77	37·12
Al_2O_3 .	23·78	11·30	Al .		26·32	−14·98	11·34
TiO_2 .	1·01	1·00	Ti .		0·72	−0·07	0·65
Fe_2O_3 .	0·83	0·80	Fe′′′ .		0·59	−0·01	0·58
FeO .	6·31	4·70	Fe″ .		4·98	−1·60	3·38
MnO .	0·09	0·06	Mn .		0·07	−0·03	0·04
MgO .	1·87	6·80	Mg .		2·63	+6·07	8·70
CaO .	0·56	26·50	Ca .		0·55	+23·84	24·39
Na_2O .	0·71	0·30	Na .		1·30	−0·80	0·50
K_2O .	1·85	1·10	K .		2·23	−1·03	1·20
P_2O_5 .	0·27	0·05	P .		0·21	−0·17	0·04
H_2O^+ .	0·68	3·70	OH .		2·41	+9·51	11·92
H_2O^- .	0·05	0·25					
Total .	99·87	99·76					
Sp. Gr.	3·06	2·74					
Ga .	20	15			16	−5	11
Cr .	65	70			53	−3	50
V .	90	100			71	+1	72
Mo .	*	*			—	—	—
Sn .	*	*			—	—	—
Li .	10	85			83	+549	632
Ni .	35	45			35	+4	39
Co .	20	22			19	0	19
Sc .	20	*			24	−24	—
Zr .	550	600			342	−3	339
In .	*	N.D.			—	—	—
Y .	65	*			41	−41	—
La .	120	*			49	−49	—
Sr .	150	45			101	−75	26
Pb .	*	*			—	—	—
Ba .	350	150			145	−89	56
Rb .	85	50			55	−25	30
Tl .	*	N.D.			—	—	—
Cs .	*	*			—	—	—

1. *Kyanite-garnet schist :* Gartally Burn, Glen Urquhart. Major constituents (percentage weight, oxides). *Analysis* by classical method, G. H. Francis. Trace constituents (parts per million by weight). *Spectrography*, S. R. Nockolds.

2. *Prehnite-pectolite skarn :* Sgòr Gaoithe, Glen Uruhart. Major constituents (percentage weight, oxides). *Analysis* by rapid method, D. I. Bothwell. Trace constituents (parts per million by weight). *Spectrography*, S. R. Nockolds.

1a† Analysis 1 recalculated to cation percentage. Major elements as parts per million × 10⁻⁴, trace elements as parts per million.

2a† As with 1a.

* Present, but below the limit for quantitative determination of this element (see Nockolds & Allen, 1953).
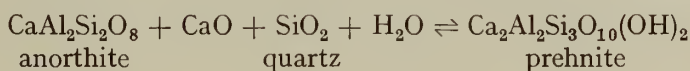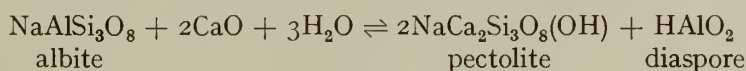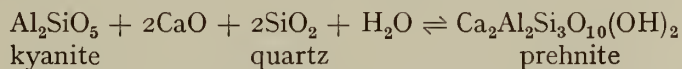
† To calculate major and trace constituents to cations (p.p.m.) the following steps were adopted :

For Analysis 1 (classical method) :
  (1) Ga, Cr, V, Sc, Zr, Y, La were converted to oxides and the total was subtracted from Al_2O_3 ;
  (2) Sr was converted to oxide and subtracted from CaO ;

In their present state the garnets are cut through and enveloped by prehnite aggregate from the groundmass.

The replacement of quartz, plagioclase, and kyanite of the original schist by pectolite, prehnite, and, to a smaller extent, diaspore, may be represented by the addition of only lime and water to the original assemblage, e.g. :

$$\underset{\text{kyanite}}{Al_2SiO_5} + 2CaO + \underset{\text{quartz}}{2SiO_2} + H_2O \rightleftharpoons \underset{\text{prehnite}}{Ca_2Al_2Si_3O_{10}(OH)_2}$$

$$\underset{\text{albite}}{NaAlSi_3O_8} + 2CaO + 3H_2O \rightleftharpoons \underset{\text{pectolite}}{2NaCa_2Si_3O_8(OH)} + \underset{\text{diaspore}}{HAlO_2}$$

$$\underset{\text{anorthite}}{CaAl_2Si_2O_8} + CaO + \underset{\text{quartz}}{SiO_2} + H_2O \rightleftharpoons \underset{\text{prehnite}}{Ca_2Al_2Si_3O_{10}(OH)_2}$$

The absence of amphiboles and pyroxenes from these skarns is noteworthy. The bulk composition of the skarns, as will be shown, might be expected to favour the growth of one or both of these minerals. Some undiscovered chemical bar to their formation, perhaps related to the very high water content of the skarns, must have operated.

The scope of the metasomatism may be studied in Table XII where the chemical analyses, with trace elements, for un-injected material[1] and the skarn product are set down. Major and trace elements have been recalculated to atomic percentages (Eskola, 1954), and gains and losses are indicated. Although there is only one analysis of kyanite schist from Glen Urquhart available, and some variation in the chemistry of that rock type definitely occurs, the possible departure of the analysis from that of the skarn's host rock must be slight in comparison with the metasomatic changes here recorded.

There has clearly been a massive accession of lime to the skarn, together with a small but definite rise in magnesia. The mobility of magnesia in the skarns has already been noted. Hydroxyl has notably increased, suggesting the hydro-thermal nature of the metasomatism, whilst among the trace elements there has been a large gain in lithium. The remaining elements remain almost steady, or have decreased in percentage. The decreases are probably related solely to the increase in Ca, Mg, and OH. No field evidence has been observed for removal of any of

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[1] The initial material, kyanite–garnet–muscovite–biotite–plagioclase–quartz schist, will be described fully in the forthcoming publication on alkali metasomatism in Glen Urquhart.

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(3) Ni and Co were converted to $Ni_2P_2O_7$, $Co_2P_2O_7$ and subtracted from $Mg_2P_2O_7$, the difference was converted to MgO ;

(4) Rb was converted to Rb_2PtCl_6 and subtracted from K_2PtCl_6 in the alkali estimation ;

(5) Li was converted to LiCl and subtracted from NaCl in the alkali calculations ;

(6) The weights (p.p.m.) of constituents thus revised were converted to cations and recalculated to parts per million.

For Analysis 2 (rapid method, alumina by difference from total R_2O_3) :

(1) Ga, Cr, V, Zr were converted to oxides and subtracted from Al_2O_3 ;

(2) As for (6) in Analysis 1.

the chemical constituents of the rock with fixation elsewhere.   This one-way meta-
somatism therefore implies expansion of the rock during injection.   Strontium and
barium, which are scarce in the limestone (Table III) have not, apparently, followed
calcium in the metasomatism.   As with some of the other elements the decreases
in Sr and Ba may be relative, rather than absolute, in this case

Summary.   A metasomatic episode has occurred after the folding and meta-
morphism of the sediments of the Moine Series and the intrusion of the serpentinite
mass in Glen Urquhart.   Some of the metasomatic rocks show clearly the replacement
of a regionally metamorphosed mineral assemblage and fabric by metasomatic
mineral assemblages.   The metasomatism is linked with neighbouring alkali
injection, pegmatitic invasion, and feldspathization.   In the area here described,
remote from the centres of alkali metasomatism, only veins bearing silica and
volatiles have penetrated.   They appear to have picked up alumina from a kyanite
schist horizon (as shown by quartz–kyanite veins in this bed) and lime from the
(structurally) underlying metamorphosed limestone (as shown by quartz veins
cith calc-silicates in and near this bed).   Under the influence of metasomatic fluids
these two constituents have mingled to form calc-alumino-silicate rocks at the
junctions of the two beds.   These rocks may be regarded as reaction skarns.
Volume-for-volume replacements cannot generally be demonstrated.   Some of
the skarns possess tightly folded and lineated fabrics which may be palimpsests[1]
after the fabric of the regional metamorphism, but may equally reflect volume
increases during metasomatism, as suggested by Poldervaart (1953).   Other skarns
have cavernous crystallization, reflecting different formation conditions and perhaps
slightly different age.

The mineralogy of the skarns is on the whole simple.   Minerals of the epidote
group, plagioclases, phlogopite, amphiboles, and pyroxenes are dominant.   The
amphiboles are closely comparable to the type " edenite " of Edenville, New York
(Rammelsberg, 1858).   The term " edenite " is examined and it is concluded that
it is an unnecessary name for amphiboles close to the original material in composition,
which are simply common hornblendes.   Still less desirable is its use for the
theoretical amphibole formula $NaCa_2Mg_5AlSi_7O_{22}(OH)_2$, remote from the composition
of the original material, and unrepresented by any amphibole analysis.

A small group of skarns, differing from the rest, is characterized by the less
common minerals prehnite, pectolite, diaspore, and xonotlite.

Mineralogical and chemical evidence suggests that magnesia, in lesser amount,
accompanied the lime during the skarn formation.   The limestone is of a somewhat
magnesian composition.   Iron oxide (e.g. from the pelitic rock) has not played such
a positive rôle in the metasomatism.   Some skarns have a moderate iron content,
others little or none.   In the analysed examples strontium and barium have not
followed calcium in the metasomatism.   Lithium is definitely increased and there
is a large accession of water.

The position of the skarns as intermediate reaction products between kyanite-
schist and limestone can be represented on the ACF diagram (Text-fig. 10).   Skarn

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[1] *Palimpsest structure :*   A structure of metamorphic rocks, due to the presence of remnants of the
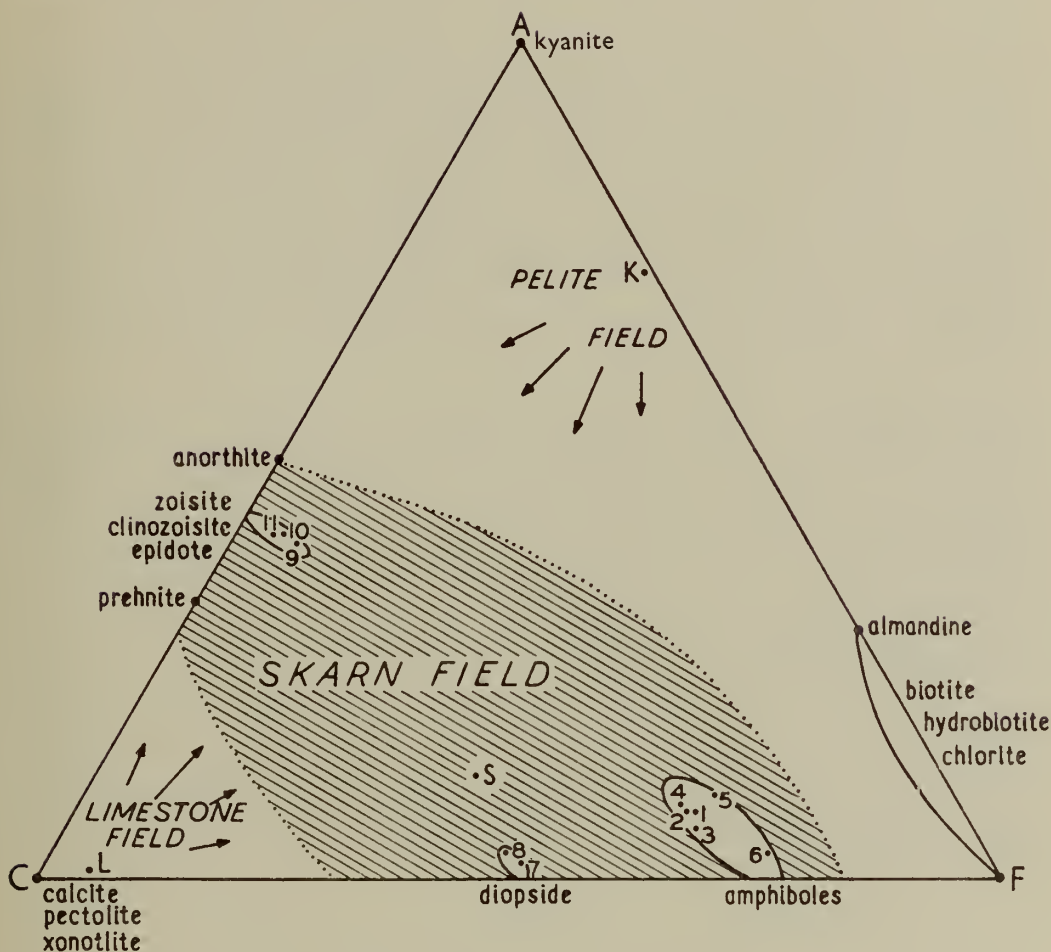original texture of the rock.   [*Dictionary of Geol. Terms.*]

FIG. 10. ACF triangle, for rocks with excess silica, showing the plots of rocks and minerals of the skarns and related rocks at Glen Urquhart. Arrows indicate the chemical contributions made by the two sedimentary rock types to the reaction skarns which have formed between them .

K, kyanite–garnet schist (Table XIV, 1) ;
S, prehnite–pectolite skarn (Table XIV, 2) ;
L, limestone (Muir *et al.*, 1956, see Table III of this study) ;
1, magnesia-rich hornblende (Table VI, 1) ;
2, magnesia-rich hornblende (Table VI, 2) ;
3, magnesia-rich hornblende (Table VI, 3) ;
4, tremolite (Heddle, 1901, vol. II) ;
5, " edenite " (Heddle, 1901, vol. II) ;
6, " edenite " (Heddle, 1901, vol. II) ;
7, salite (Table IX, 1) ;
8, diopside (Table IX, 2) ;
9, 10, 11, zoisites (Heddle, 1901, vol. II).

minerals analysed in the present study, and by Heddle (1901), together with analyses of kyanite schist, prehnite–pectolite skarn, and limestone, are plotted on this diagram. The varied mineral assemblages and the varying proportions of minerals within each assemblage amongst the skarns suggest that a large number of rock analyses would be necessary in order adequately to define the chemical field of these skarns.

It is simpler, and almost as accurate, to represent them in a field in the ACF diagram (Text-fig. 10) extending between anorthite, " epidote ", tremolite, and diopside (all of which are found, in some cases, as almost monomineralic rocks[1]) and extending from this area some distance towards the C corner and the F corner, respectively, where further skarn minerals are plotted. It can be seen that the plot point of the analysed rock (Text-fig. 10) lies close to the fields of pyroxene and amphibole, yet contains neither mineral.

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[1] Monomineralic rocks or rocks with only traces of minerals other than their dominant constituent are a feature of the Glen Urquhart area. The following have been collected as rocks (asterisks denotes those that are strictly monomineralic) : antigorite*, biotite, calcite, diopside, gedrite, kyanite, oligoclase*, pectolite*, quartz*, serpentine, tremolite, hornblende *cf.* " edenite ", vermiculite, zoisite.

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PLATE 8

Fig. 1. Marble (paragenesis No. 14, Table II), from the largest limestone quarry, Upper Gartally. A very pure variety with minor amounts of quartz, plagioclase, phlogopite, and sphene set in calcite. The calcite has simple polygonal boundaries, $(01\bar{1}1)$ cleavages and $(01\bar{1}2)$ glide lamellae. Magnification 25 ×, crossed nicols.

Fig. 2. Amphibolic marble (paragenesis No. 11, Table II), from the above quarry. Fasciculitic and plumose groups of amphibole (called " edenite " by Heddle) in limestone ; much sieving of the amphibole by blebs of calcite, larger crystals at the top of the field. Magnification 25 ×, crossed nicols.

Fig. 3. Zoisite–quartz rock associated with the limestones (paragenesis No. 18, Table II), Upper Gartally Farm House. Low relief, quartz ; high relief zoisite. Actinolite needle of late growth in transverse section, at the centre of the field. Magnification 25 ×, ordinary light.
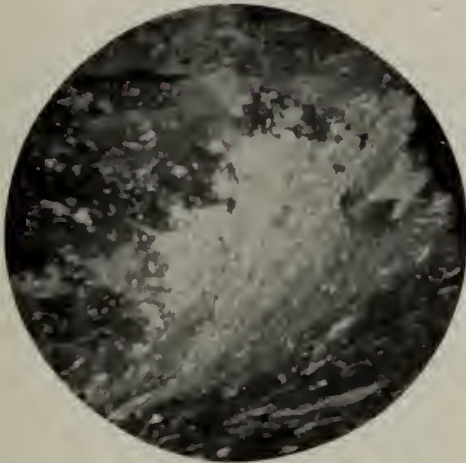
Fig. 4. Zoisite–quartz–tremolite–diopside rock associated with marble (paragenesis No. 19) Upper Gartally Farm House. Abundant late spearing growth of actinolite transecting the ground of α-ziosite, diopside (note pyroxene cleavage), and quartz. Magnification 25 ×, ordinary light.
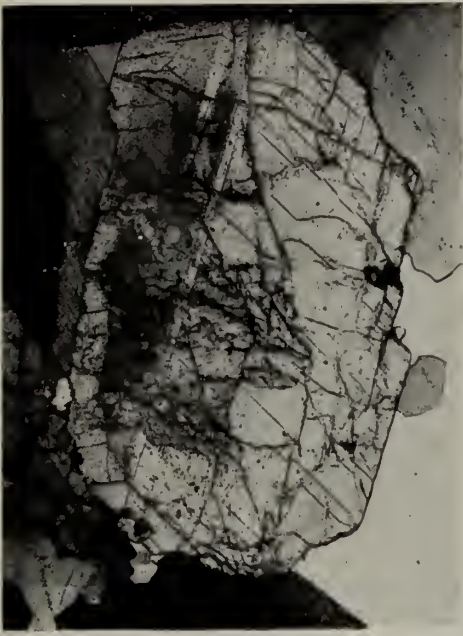
PLATE 8

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2

3
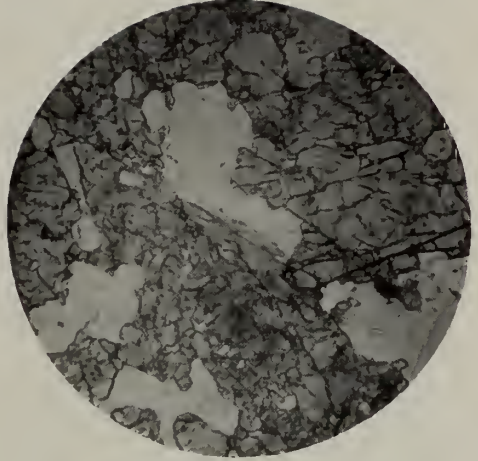
4

PLATE 9

FIG. 1. Large twinned clinozoisite-epidote crystal in epidosite, Torr Buidhe. The crystal is cut normal to *b*, and shows crystal faces, the (100) twin plane, and the (001) cleavage. The distribution of zones is shown diagrammatically in Text-fig. 7*a*. Magnification 25 ×, crossed nicols.
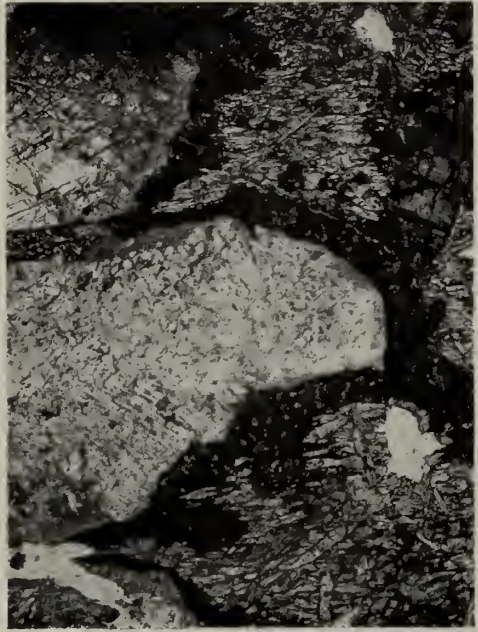
FIG. 2. Prehnite in diopside rock, Sgòr Gaoithe. Note fine needles of actinolite at lower left. Magnification 95 ×, crossed nicols.

FIG. 3. Zones in metasomatic rock, Sgòr Gaoithe. At the right of the field are matted needles of actinolite, with a large crystal of sphene. To the left is a dark, " mossy " zone of clinozoisite, and to its left are large, turbid crystals of plagioclase. Magnification 20 ×, plane light.

FIG. 4. Twinned clinozoisite which has replaced a relict core of kyanite within a mantle of " shimmer-aggregate " white mica. Elsewhere in the field are somewhat altered biotite, muscovite, and plagioclase altering to prehnite. Magnification 12 ×, crossed nicols.
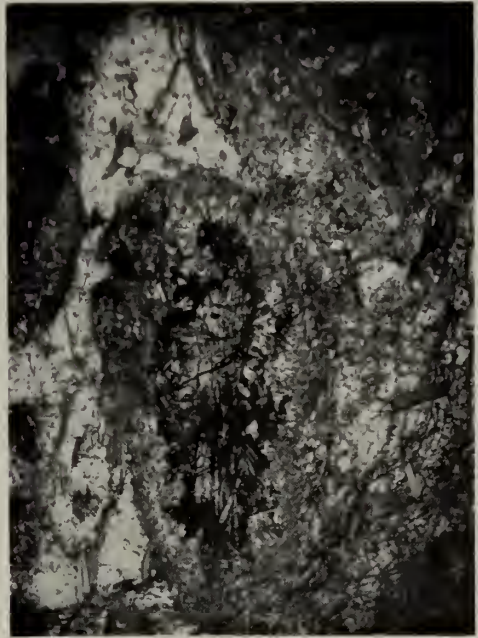
Bull. B.M. (N.H.) Min. 1, 5

PLATE 9

1

3

2

4

Bull. B.M. (N.H.) Min. 1, 5

PLATE 10

LEGEND

☐ Psammitic gneiss

▨ Kyanite schist

▤ Limestone

⛝ Serpentinite

〜 Alluvium

✕ Limestone quarry

■ Skarns of Group I

● " " " II

◆ " " " III

SCALE
0 —————— 1000 FT.
0 —————— 300 M

N

LOCH MAOLACHAIN

TORR BUIDHE

LOCHAN AN
TORRA BHUIDHE

△ BEINN A'
GHAIRCHIN

LOCHAN SGÒR GAOITHE
+ Balnagrantach

Upper +
Gortally

△ SGÒR
GAOITHE

Lower
Gortally

MILTON

+ Kilmichael

RIVER ENRICK